Performance Metrics
Results to Date

June 2001
Report

INTRODUCTION

This is the third semi-annual report on Free Flight Phase 1 (FFP1) performance metrics. The intent is to describe analyses and results for FFP1 implementations over the last 6 months. The majority of new analyses relate to the Traffic Management Advisor (TMA) and the Passive Final Approach Spacing Tool (pFAST). Surface Movement Advisor (SMA) implementation is complete including several additional sites. Both the June 2000 report and the December 2000 report, available on the Free Flight website (http://ffp1.faa.gov), display the details of the SMA results. Collaborative Decision Making (CDM) is near complete and the June 2000 report contains a thorough analysis.

We continue to collect metric data for the User Request Evaluation Tool (URET) prototype sites. These sites have the same functionality as the Core Capability Limited Deployment (CCLD) sites scheduled for initial daily use in early 2002. The results from the URET prototype sites reflect expected CCLD benefits.

Highlights from the analyses to date (June '01) are as follows:

URET: Continued increase in direct routings and combined cost savings of more than $1.5 million for Indiannapolis and Memphis en route centers (Section **2.4.1**)

pFAST: Increase in arrival capacity at Los Angeles International Airport of between 1.5 and 3.5 percent (Section **3.4.1**)

TMA: Continued increase in operations rate of more than 3 percent at Minneapolis International Airport (Section **4.4.5**)

SMA: Continued anecdotal evidence of benefits to airlines (Section **5.2**)

We established an initial set of performance metrics early in the FFP1 program in collaboration with aviation stakeholders. The metrics team now includes analysts from the following organizations: MITRE Center for Advanced Aviation System Development (CAASD), The CNA Corp. (CNAC), TASC Inc., NEXTOR, Seagull Technology, and Analytics Associates. The purpose of these metrics is to establish accountability, provide near term feedback to implementation teams, and provide a basis for future free flight investments.

The primary FFP1 performance goals are to increase capacity (airport and airspace), reduce flight time and/or distance, and improve fuel efficiency, while maintaining system safety levels. For user benefit calculations, these metrics translate into delay savings after normalization for factors such as weather and demand.

To assure a full understanding of how each new tool affects operational performance, the metrics include both "upstream" and "downstream" measures. For example a metering tool such as TMA has no direct link to taxi times, however, we are interested in any significant ground movement changes linked to increased arrival rates. Other measures, such as "angle of degrees turned" or "runway balancing," provide supporting evidence for the accuracy of the primary measurements.

Although this document is not intended to provide benefit forecasts for each tool at additional sites, we have attempted to show how the metric results at each site translate into user benefits.

If you have questions or comments on this document or the FFP1 metrics program please contact Dave Knorr at 202 220-3357.

TABLE OF CONTENTS

Section **Page**

Introduction .... *i*

1.0 SAFETY *1*

1.1 Description **1**

1.2 Methodology **1**

1.3 Analysis and Results **2**

1.4 Next Steps **2**

2.0 USER REQUEST EVALUATION TOOL (URET) *4*

2.1 Description **4**

2.2 Operational Use at ZID/ZME **5**

2.2.1 Procedures 6
2.2.2 Procedures and Benefits Team 7
2.2.3 Good Practices 7

2.3 Translating URET Metrics into User Benefits **7**

2.4 Analysis and Results: ZID and ZME **8**

2.4.1 Reduction in NMI Flown 8
2.4.1.1 Lateral Amendments 8
2.4.1.2 Excess Distance and En Route Distance Between Selected City Pairs 10
2.4.2 Lifting of Static Altitude Restrictions 13

2.5 Future Benefits Work **13**

3.0 PASSIVE FINAL APPROACH SPACING TOOL (pFAST) *15*

3.1 Description **15**

3.2 Operational Use at LAX **15**

3.3 Translating pFAST Metrics into User Benefits **16**

3.4 Analysis and Results: SCT/LAX **17**

3.4.1 Difference between Actual Rate and Acceptance Rate 19
3.4.2 Flight Times and Distances 22
3.4.3 Alternative Analysis of Delay 25

4.0 TRAFFIC MANAGEMENT ADVISOR (TMA) *28*

4.1 Description **28**

4.2 Operational Use at ZMP/MSP; ZDV/DIA **28**

4.3 Translating TMA Metrics into User Benefits **30**

4.4 Analysis and Results: ZMP/MSP **31**

4.4.1 Summary of Results To Date 31

4.4.2 Airport Acceptance Rate 32
4.4.3 Actual Arrival Rate 34
4.4.4 Difference between Actual Rate and Acceptance Rate 40
4.4.5 Operations Rate 41
4.4.6 Flight Times 43
4.4.7 Taxi Times 45

4.5 Preliminary Analysis: ZDV/DIA 46

5.0 SURFACE MOVEMENT ADVISOR (SMA) 48

5.1 Description 48

5.2 Reported Anecdotal Benefits (Updated) 48

6.0 REFERENCES 50

7.0 Acronyms 51

APPENDIX A. Description of Box Plot 1

FIGURES

Section **Page**

Figure 2-1. URET Directs as a Subset of Total Directs: ZID 5
Figure 2-2. URET Directs as a Subset of Total Directs: ZME 6
Figure 2-3. Distance Saved - All Laterals During Sampling Hours: ZID and ZME 9
Figure 2-4. Excess Distance: URET CCLD Sites 10
Figure 2-5. En Route Distance Trend: ZME 12
Figure 2-6. En Route Distance Trend: ZID 12
Figure 3-1. Example of Arrival Demand and AAR at LAX 18
Figure 3-2. Arrival-Acceptance Rate by AAR: All Data 19
Figure 3-3. Arrival-Acceptance Rate by AAR: Equal Demand Period 20
Figure 3-4. Weighted Comparison of Arrival and Acceptance Rate: All Data 21
Figure 3-5. Weighted Comparison of Arrival and Acceptance Rate: Equal Demand Period 21
Figure 3-6. LAX Range Rings for Flight Time and Distance Metrics 22
Figure 3-7. Flight Time between Arcs during Busy Periods 23
Figure 3-8. Flight Distance between Arcs during Busy Periods 24
Figure 3-9. Hypothetical Arrival and Departure Curves at an Airport 25
Figure 3-10. Queuing Diagram for 11/7/00 26
Figure 3-11. Queuing Diagram for 12/1/00 26
Figure 3-12. Observed vs Predicted Delays 27
Figure 4-1. ZDV/DIA Total Monthly Metering Times 29
Figure 4-2. ZMP/MSP Total Monthly Metering Times 30
Figure 4-3. Acceptance Rate Comparison of Means 33
Figure 4-4. MSP Arrival Rate, 3 November 2000 34
Figure 4-5. MSP Weekday Arrival Rates, November 2000 35
Figure 4-6. Actual Arrival Rate Comparison of Means 36
Figure 4-7. Comparison of Actual Arrival Rate and AAR 41
Figure 4-8. Operations Rate Comparison of Means 42
Figure 4-9. MSP Range Rings for Flight Time Metrics 44
Figure 4-10. Taxi Time Statistics at MSP Pre and Post TMA Deployment 46
Figure 4-11. Arrival Demand and AAR at DIA during a day when metering occurred 47

Figure A-1. Sample Box Plot **...** ***1***

Figure A-2. Side-by-Side Box Plot Comparison **..** ***2***

TABLES

Section **Page**

Table 2-1. Comparison Airspace and Traffic ZID: ZME and ZDC......................................11

Table 2-2. History of Static Altitude Restriction Removal: ZID..13

Table 3-1. pFAST Flight Time and Flight Distance Savings..24

Table 4-1. AAR Analysis of Variance...33

Table 4-2. Actual Arrival Rate Analysis of Variance..36

Table 4-3. Actual Arrival Rate Regression Results...39

Table 4-4. Operations Rate Analysis of Variance 42

Table 4-5. Operations Rate Regression Model...43

Table 4-6. TMA Flight Time Savings (sec.) 45

1.0 SAFETY

1.1 Description

FFP1 capabilities are intended to provide benefits to users while maintaining the current high level of system safety. Safety has been the fundamental FAA objective since the agency was established, and it continues to underlie the development and implementation of every FFP1 tool. Safety objectives are reflected throughout the *Free Flight Phase 1 Program Master Plan,* the document that describes the implementation process for FFP1 capabilities.

To help meet these safety objectives, FFP1 management established a risk management process that tracks the performance of each FFP1 tool throughout the implementation phase. The FFP1 risk management team identified safety as one of two critical risk areas. To mitigate safety risks, service providers have been and will be involved in both the design and validation processes for all FFP1 capabilities.

FFP1 safety metrics are being used to support the FFP1 safety evaluation, thereby helping to ensure that no fielded tool will inadvertently cause a net reduction in system safety. As with all FFP1 metrics, the FFP1 safety metrics reflect collaboration with Stakeholders, and a consensus among airspace users, the FAA, industry, and unions.

In the FFP1 Metrics Plan, the principal safety metrics are defined to be the change in operational errors (OEs) and operational deviations (ODs) associated with the use of the FFP1 capabilities. The plan further states that, where possible, baseline data should be segregated by conditions or factors that influence the number of OEs and ODs (e.g., weather, traffic density, communications congestion).

1.2 Methodology

The methodology being used by the FFP1 Metrics Team for the analysis of safety impact can be summarized as follows:

- Track facility ODs and OEs during a baseline period and after implementation of FFP1 capabilities, focusing on the total number of errors/deviations per facility and the number of errors/deviations attributed to one or more FFP1 capabilities.
- In cooperation with the FAA Evaluations and Investigations Staff (AAT-20), analyze OE data in detail during the baseline and post-implementation periods to identify and track underlying factors. Examples of such factors include
    - Traffic density
    - Controller readback errors
    - Communications problems
    - Inappropriate controller use of displayed data
    - FFP1 capabilities in use

- In coordination with FAA headquarters, regions and facilities, establish a process to collect pertinent information relating to OEs and ODs before and after FFP1 implementation. In particular, the Metrics Team will monitor the FAA Evaluations and Investigations Staff program to evaluate OEs and ODs as they occur. AAT-20 will advise the Metrics Team any time an FFP1 tool is identified as a factor in any OE or OD.
- Track relevant data maintained by various FAA offices and other government agencies (e.g., NASA, NTSB), including
    - Aviation Safety Reporting System (ASRS) data
    - NTSB Accident/Incident Reports
    - FAA Incident Data System
    - FAA Near Mid-Air Collision (NMAC) Database

1.3 Analysis and Results

Analysts have long recognized that aviation safety is difficult to measure. Operational errors and deviations are commonly used as metrics, even though they are often the product of a complex series of events that make tracking causes and trends difficult.

In this analysis, the first step has been to track the number of OEs and ODs at each of the Free Flight Phase One sites. This data has been taken from the FAA's Air Traffic Service Evaluations and Investigations Staff's compilation of National Airspace System (NAS)-wide OEs and ODs. No significant change in monthly OE or OD rates beyond that experienced NAS-wide can be identified from these data.

Each OE and OD at an FFP1 site has also been evaluated to see if any FFP1 tool was identified as a factor. As of 1 June 2001, no FFP1 capability has been identified as a factor in any OE or OD. In addition, no reports of FFP1 capability involvement in any accidents or incidents have been reported in the NTSB Accident/Incident Reports, the FAA Incident Data System or the FAA NMAC Database as of 1 June 2001. To date, one NASA ASRS report has been submitted (DFW, December 2000) in which a pilot claimed "the computer" (presumably CTAS) assigned his aircraft to a runway that kept them high and fast on final approach. The pilot reported that they "barely made the [descent] parameters for a stabilized [approach]." No further negative consequences from this incident have been reported.

1.4 Next Steps

As the fielding of FFP1 capabilities proceeds, the FAA will take the following steps to evaluate FFP1's safety impact:

- Continue the analysis of OEs and ODs at current and planned FFP1 sites
- Continue the comparison between OE and OD rates at FFP1 sites with those found at sites not hosting FFP1 capabilities
- In coordination with FAA AAT-20, continue to develop a capability to analyze

individual OE reports, identifying factors that may be common across multiple OEs. Possible factors include:

- Communication problems (e.g., frequency congestion, incorrect readbacks, wrong call signs)
- Timely controller use of available information.

2.0 USER REQUEST EVALUATION TOOL (URET)

URET continues to produce user benefits in both Indianapolis (ZID) and Memphis (ZME) Air Route Traffic Control Centers (ARTCCs) through increased direct routings and reduction in static altitude restrictions. This section updates previous reports with analyses of distance savings from increased direct routings and fuel efficiency gains due to fewer altitude restrictions.

2.1 Description

URET processes real-time flight plan and track data from the Host computer system. These data are combined with site adaptation, aircraft performance characteristics, and winds and temperatures from the National Weather Service in order to build four-dimensional flight profiles, or trajectories, for all flights within or inbound to the facility. URET also provides a "reconformance" function that adapts each trajectory to the observed speed, climb rate, and descent rate of the modeled flight. For each flight, incoming track data are continually monitored and compared to the trajectory in order to keep it within acceptable tolerances.

Once implemented, neighboring URET systems will exchange flight data, position, reconformance data, and status information in order to model accurate trajectories for all flights up to 20 minutes into the future. URET trajectories help the Radar Associate (RA) controller visualize the future positions of aircraft. Controllers can then address the conflicts strategically by managing their workload more efficiently, vectoring and maneuvering aircraft less, and increasing the margin of safety.

URET maintains "current plan" trajectories (i.e., those that represent the current set of flight plans in the system) and uses them to continuously check for aircraft and airspace conflicts. When a conflict is detected, URET determines which sector to notify and displays an alert to that sector up to 20 minutes prior to the start of that conflict. Trial planning allows a controller to check a desired flight plan amendment for potential conflicts before a clearance is issued. The controller can then send the trial plan to the Host as a flight plan amendment. Coordination of trial plans between sectors, which might include those of neighboring centers, may be achieved non-verbally using automated coordination capabilities. Early detection of conflicts and trial planning of resolutions helps controllers identify problems sooner, giving them more time to manage their workload more efficiently, vector and maneuver aircraft less with more strategic resolutions, and grant more user requests via the trial planning function.

These capabilities are packaged behind a Computer Human Interface (CHI) that includes text and graphic information. The text-based Aircraft List and Plans Display manage the presentation of current plans, trial plans, and conflict probe results for each sector. The Graphic Plan Display (GPD) provides a graphical capability to view aircraft routes and altitudes, predicted conflicts, and trial plan results. In addition, the point-and-click interface enables quick entry and evaluation of trial plan routes, altitudes, or speed changes and enables the controller to send flight plan amendments to the Host.

The key URET capabilities for FFP1 include:

- Trajectory modeling,
- Aircraft and airspace conflict detection,
- Trial Planning to support conflict resolution of user or controller requests, and
- Electronic flight data management.

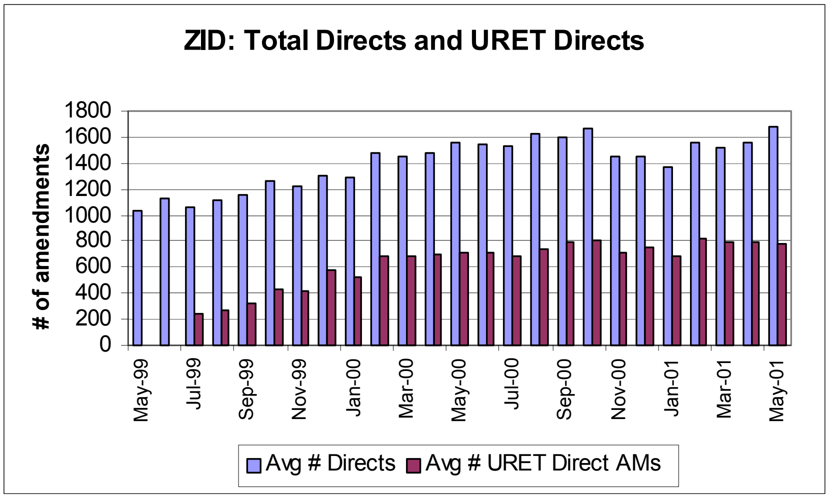
For more details about URET capabilities, benefits, and operational concept, please refer to the paper by Celio et al on the MITRE/CAASD URET web site, www.caasd.org/library/tech.docs/1999/mp99W183.pdf.

2.2 Operational Use at ZID/ZME

To date, analyses of URET's impact on operational performance are based on experience at ZID and ZME. Functionality at these sites is the basis for implementation at five additional sites beginning early 2002.

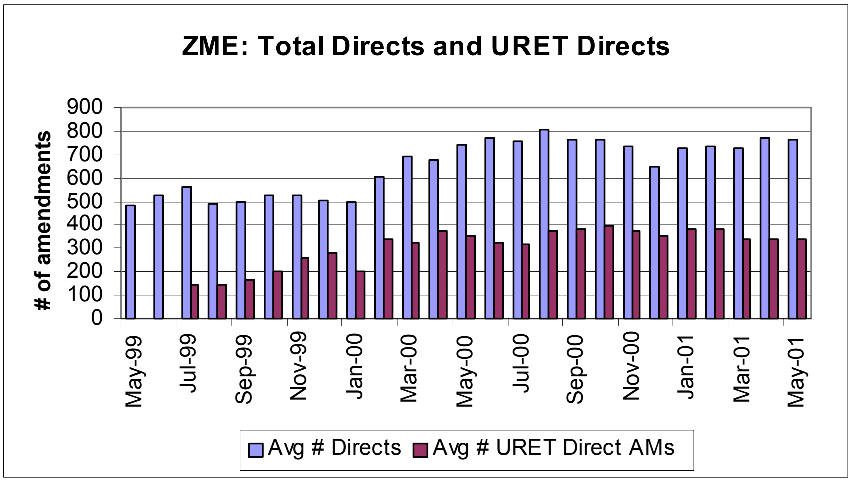
Initially, use of URET by controllers at ZID and ZME was optional. Controllers used URET primarily in high and ultra-high sectors, not in lower sectors that manage merging arrival traffic. Usage increased substantially when the URET capability to send amendments directly to the Host became available in July 1999. Controllers found that this feature substantially increased their efficiency by reducing the time to enter route amendments into the Host. URET provides a menu that lists downstream fixes that are on the aircraft's flight path. The controller can create a trial plan, review it, and send an amendment with three clicks of the mouse or track ball.

Figures 2-1 and 2-2 show the significant increase in amendments resulting in direct routes since July 1999. These charts are an indication of how improving the controllers' efficiency results in increased benefits to users.



Data: 2 days a week: Wed. and Thurs; 10 busy hours

Figure 2-1. URET Directs as a Subset of Total Directs: ZID



Data: 2 days a week: Wed. and Thurs; 10 busy hours

Figure 2-2. URET Directs as a Subset of Total Directs: ZME

While the performance metrics for URET focus on benefits during normal weather conditions, URET has also proven to be effective during adverse weather conditions. The graphic reroute capabilities of URET make it easier for the controller to enter route deviations due to weather. The graphical user interface facilitates this functionality by displaying:

- A graphic presentation of the requested flight path,
- Traffic conflicts the new route may create, and
- A text line with the new route displayed.

If the route does not interfere with normal traffic flows, the controller accepts the amendment and the aircraft's flight plan is changed. This process provides a quick and easy method of finding alternative routes around adverse weather.

2.2.1 Procedures

In order to increase controller efficiency and provide user benefits using URET, ZID and ZME implemented new local procedures, created a new organizational group within the facilities, and identified appropriate practices and techniques for use of the tool.

In November 1999, following experience with using URET to directly input amendments to the Host, a Memorandum of Understanding (MOU) was signed between the National Air Traffic Controller Association (NATCA) and the ZME ARTCC recognizing URET's value to the RA. With URET, the RA has better information that gives him/her the ability to avoid conflicts earlier, vector aircraft less, increase efficiency through smoothing workload, and respond more positively to user requests.

Recently ZID and ZME have granted waivers to the Wrong Altitude for Direction of Flight (WAFDOF) procedure. Using the additional information URET provides has reduced the need for time-consuming voice coordination usually needed for WAFDOF. In this way, using URET for WAFDOF supports more efficient use of available airspace.

ZID and ZME have also reduced the requirements for the use of paper strips for flight data management further increasing controller efficiency and service to users.

Provisions for authorization of WAFDOF, for selectively reviewing and lifting static altitude restrictions, and for reduced dependence on paper flight strips are incorporated in new national FAA Orders that are scheduled to become effective on 12 July 2001.

2.2.2 Procedures and Benefits Team

In the fall and winter of 1999-2000, ZID and ZME established Procedures and Benefits teams to review static altitude restrictions with the intent of identifying candidate restrictions that could be relaxed or lifted, testing them to determine the operational impact, and lifting those that were successfully tested. The teams agreed that without the reliable trajectories and advance warning of predicted conflicts provided by URET, they would not consider lifting static altitude restrictions. The ZID team has been particularly successful in reviewing and lifting restrictions.

2.2.3 Good Practices

The FFP1 Program Office, MITRE/CAASD, and the ZID and ZME operational personnel working together developed a set of “operating recommendations” or “best practices” in the use of URET to maximize benefits and increase the operational utility. Formal site documentation and ownership of recommendations for effective use of URET constituted a significant step toward the integration of URET into sector operations. These practices are being integrated into the training program for URET CCLD.

2.3 Translating URET Metrics into User Benefits

The primary metrics that address benefits to NAS users are distance/time saved, static altitude restrictions lifted, and increased airspace capacity. Distance saved and removed altitude restrictions translate into reduced operating costs and improved fuel efficiency. Distance is used because it normalizes for winds and can be translated into reduced flight time. Future reports will study the ability to increase en route airspace throughput.

For distance savings, we have employed several analytical measures to determine a nominal reduction in distance facilitated by URET. The measures include:

- Change in miles flown because of lateral amendments
- Change in average distance flown through each Center’s airspace
- Change in distance flown for specific city pairs

The analysis of changes in lateral amendments is the most closely tied to URET’s direct operational impact and is our primary approach. Each of these methods indicates a reduction in distance flown comparing the period prior to July 1999 with the post July period. July 1999 marked the first time that controllers were able to input URET amendments directly into the Host computer. This dramatically improved URET's ability to assist controllers in providing more direct routes. Our analyses indicate a reduction in flight distance by approximately 1 mile per flight for flights operating during the 10 peak hours of the day, which translates into more than $1,875,000 per month. Section 2.4.1 details the analyses supporting the above savings.

In addition to distance savings, we have observed improvements in fuel efficiency resulting from removing altitude restrictions. Static altitude restrictions are in place to help controllers manage traffic safely without verbal communication between sectors. These restrictions help separate traffic flows. Since the summer of 1999, controllers at ZID and ZME have been reviewing static altitude restrictions to determine which ones are candidates for modification or removal. Operational personnel at both sites have said that they are not willing to lift restrictions without the 20 minute look-ahead provided by URET of incoming traffic and predicted conflicts. The sites, therefore, have identified *intra*-facility restrictions as candidates for removal. With the deployment of URET CCLD, *inter*-facility restrictions between URET sites will become candidates for evaluation and possible removal.

Airlines have provided information on the average fuel burn per aircraft based on aircraft type and altitude to help determine the savings from allowing aircraft to fly at their preferred altitude longer. The savings to users from the removal of altitude restrictions at ZID is in excess of $900,000 annually.

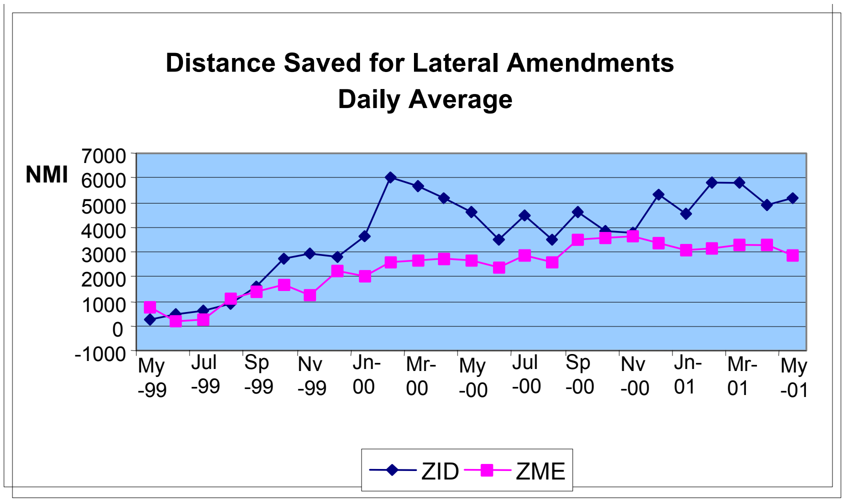
2.4 Analysis and Results: ZID and ZME

This section presents the results of analyses at ZID and ZME of reduction in miles flown and static altitude restrictions lifted. The primary measure used for the reduction in miles flown metric is based on data captured directly from use of the tool through analysis of all lateral amendments input to the Host. Two other metrics, Excess Distance in Center, and Savings by City Pairs in En Route Airspace, support the results derived through the analysis of lateral amendments and are discussed later in this section. The primary measure used for savings from the lifting of static altitude restrictions is based on data provided by airlines on fuel burn at various altitudes by aircraft type.

2.4.1 Reduction in NMI Flown

2.4.1.1 Lateral Amendments

Lateral amendments are defined as changing the direction of an aircraft without changing the altitude. They include penalties (e.g., turns to avoid congested and heavy weather areas) as well as savings in distance. The metric measures the average daily sum of nautical miles (nmi) changed as the result of an amendment; i.e., the distance from the point of the amendment to the destination airport. It includes all lateral amendments entered into the Host for the specified time, not only URET amendments. The intent of measuring changes in lateral distance is to determine if URET is enabling shorter routes. Reductions in distance may result from the addition of direct routes or from decreasing the amount of excess distance needed to avoid congestion or weather. To determine the distance saved by URET-enabled lateral amendments, we compare the lateral distance saved through all amendments before July 1999 to that saved after this date. July 1999 is the period when the URET capability to enter Host amendments became available. The "pre-URET" period is limited to May and June of 1999 when detailed Host data and URET trajectory projections were first collected. Data for Figure 2-3 includes all Host laterals during the ten busiest hours at ZID and the eight busiest hours at ZME on the two most heavily trafficked days of the week (Wednesday and Thursday). Distance saved is from the point of the amendment to the destination airport. The "savings" have increased from approximately 500 nmi average daily savings (May and June) to over 4000 nmi. This is a result of an increase in entry of direct amendments (i.e., laterals that reduce distance).



Data: 2 days a week: Wed. and Thurs 10 Busiest Hours: ZID 1300 – 2300; ZME 1400 - 2200.

Figure 2-3. Distance Saved - All Laterals During Sampling Hours: ZID and ZME

The determination of dollars saved by reduction in distance flown is based on information from the Air Transport Association (ATA). The assumed flying time is 7 miles a minute. The ATA official preliminary delay cost estimate for 2000 is $62.50 per airborne minute When ZID and ZME are averaged together, distance saved is 3500 nmi per Center over the baseline (before the controller could send amendments directly to the Host via URET), which is 500 minutes per Center. At 62.50 per minute the savings per month is $937,500 or $1,875,000 for both Centers. The savings estimate is very conservative as nmi saved is calculated for only the 10 busiest hours. If savings were calculated for the complete day, the nmi, and dollars saved would increase.

The savings per aircraft from all lateral amendments at ZID and ZME was calculated from May 1999 through May 2001. The average daily savings increase from the baseline (May and June 1999, before the controller could send amendments to the Host via URET) is approximately 1 nmi per aircraft for ZID and .9 nmi per aircraft for ZME (see Figure 2-3). The figures for April and May 2001 are affected by the COMAIR strike, which started in late March

2.4.1.2 Excess Distance and En Route Distance Between Selected City Pairs

This section discusses two other metric analyses which support the lateral distance savings discussed above: Excess Distance within a center minus the optimum distance (i.e., the great circle route), and savings in total en route distance (not only ZID and ZME) between selected city pairs.

2.4.1.2.1 Excess Distance

Excess distance is the difference between the actual distance flown and the great circle distance from center entry to exit points. The great circle route is the default standard for the most efficient route of flight, not taking variable conditions such as wind direction and velocity into account. The smaller the excess distance flown, the more efficient the flight. The excess distance flown per aircraft from January 2000 through April 2001 at ZID and ZME is compared with the other URET CCLD centers (see Figure 2-4). The new URET CCLD centers are being baselined to determine the impact of URET on distance flown. This metric will be monitored over time to determine the impact of URET on flight length within the center.

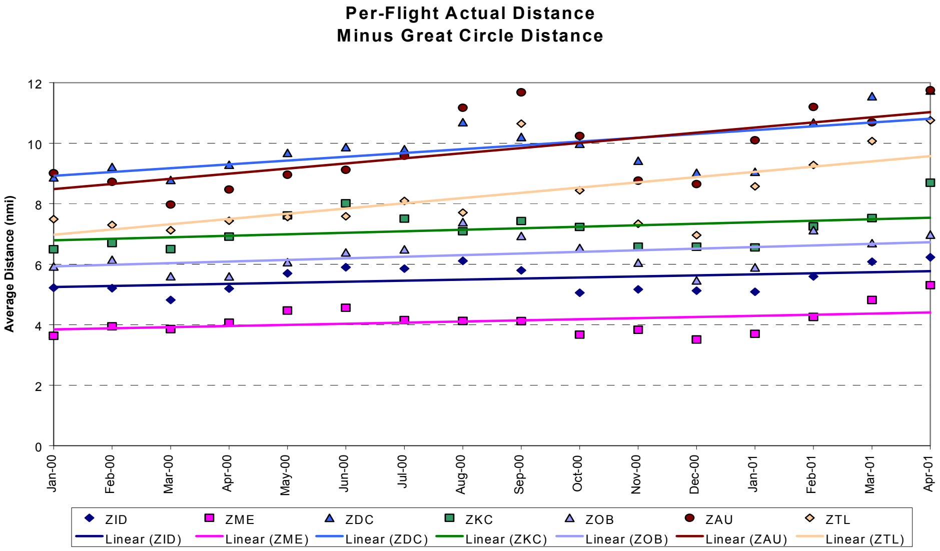


Figure 2-4. Excess Distance: URET CCLD Sites

The excess distance flown metric is calculated for all days of the month. The metric shows a slight increase from January 2000 through April 2001 for both ZID and ZME. Excess distance increased at ZME from slightly less than 4 nmi per aircraft to slightly over 4 nmi per aircraft; at ZID the increase was from about 5.5 to 5.8 nmi per flight. These URET centers, however, had the least excess distance of any of the seven URET CCLD centers. The difference between ZID and ZDC is particularly notable. ZDC has about the same traffic as ZID (see Table 2-1) and about 80 percent more airspace. The excess distance for ZDC (almost 11 nmi in April 2001) and the upward slope (from approximately 9 to 11 nmi) is not accounted for by either quantity of airspace or quantity of traffic. Traffic complexity and route structure may significantly affect aircraft routing. The impact of URET will be monitored over time at all the sites.

Table 2-1. Comparison Airspace and Traffic ZID: ZME and ZDC

Comparative Airspace and Traffic ZID: ZME and ZDC				
	Sq. NMI Airspace	**IFR Traffic 2000***	**Airspace Relation to ZID**	**Traffic Relation to ZID**
ZID	**73,000**	**2,685,000**		
ZME	**116,000**	**2,232,000**	**Approx. 60% more**	**Approx. 17% less**
ZDC	**130,000**	**2,772,000**	**Approx. 80% more**	**Slightly more**

ARTCC Activity, April 2001, US DOT, FAA, Administrator's Fact Book

2.4.1.2.2 En Route Distance

The En Route Distance metric takes a broader look at the impact of URET on flights that *traverse* ZID or ZME airspace. One question of interest is whether a flight distance savings realized in ZID or ZME would be offset or reduced by an increase in flight distances in other ARTCC facilities. Unlike the previous metrics, that analyze the impact of URET within ZID or ZME, this analysis explores this distance savings question by looking at the entire "en route" portion of a flight, not just that within ZID or ZME.

To answer this question, the en route distance was calculated for flights traversing ZID or ZME airspace over a 2-year period (May 1999 to May 2001). En route distance is calculated by summing the straight-line distance between reported aircraft positions, beginning with the entry point of a flight into en route airspace (approximately 40 nmi from the departure airport) and ending with the exit point of a flight (approximately 40 nmi from the destination airport). For each of the selected analysis days, the average en route distance was calculated for each of ten designated city pairs. In addition, a weighted average was used so that the overall average would not be distorted from one data set to another by variations in the number of flights between particular city pairs. The results are illustrated in Figures 2-5 and 2-6

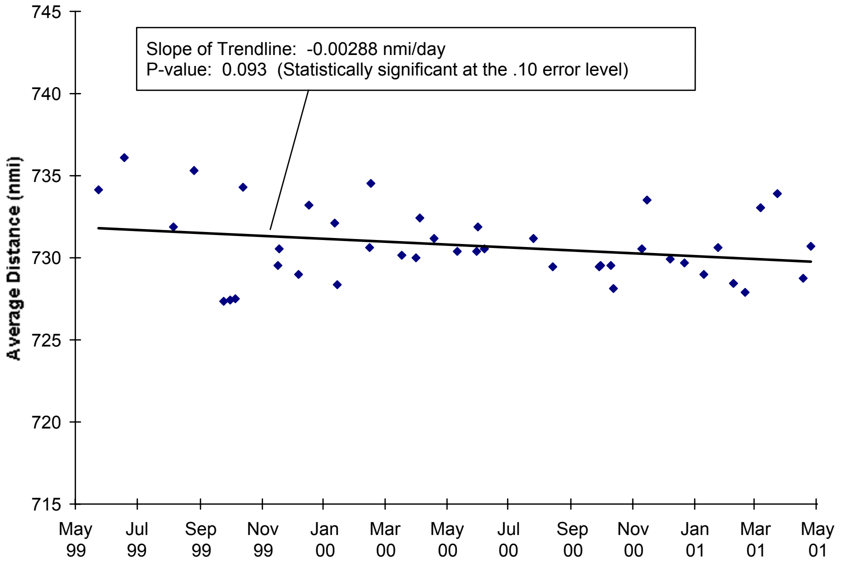


Figure 2-5. En Route Distance Trend: ZME

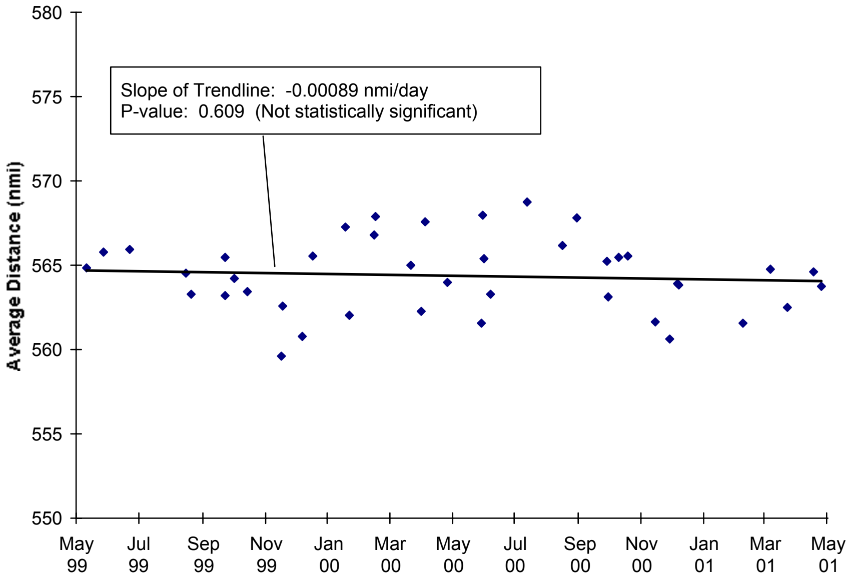


Figure 2-6. En Route Distance Trend: ZID

In summary, the en route trend indicated a slight, but significant, decrease in distance between city pairs for ZME; the result for ZID shows a slight decline in average distance, but it is not statistically significant. Further analysis is required to draw any stronger conclusions. We are starting to collect baseline data on the other URET CCLD sites in order to track en route distance. The data collection and analysis will continue after URET CCLD is deployed.

2.4.2 Lifting of Static Altitude Restrictions

The Procedures and Benefits teams at ZID and ZME were established to evaluate static altitude restrictions for modification or removal. Both centers clearly indicated that they were unwilling to consider lifting restrictions with non-URET centers. URET provides controllers with advance information; it makes them less dependent on rigidly structured airspace to manage traffic. ZME quickly determined that most of the candidate static altitude restrictions were inter-facility, imposed by other centers, and could not be evaluated for removal until URET CCLD provided an inter-facility URET capability. The ZID team, however, has been meeting monthly in-house since the fall of 1999. It also has been meeting quarterly with airline representatives to coordinate activities and work cooperatively for increased benefits to users of the NAS.

The Procedures and Benefits team at ZID identifies candidate restrictions for evaluation, tests the restrictions by lifting or modifying them for a period of time (usually two weeks) to determine the feasibility of permanent modification or removal, and determines if they can be permanently modified or removed. By removing altitude restrictions at sector boundaries, aircraft can fly longer at higher (more fuel efficient) altitudes. Results of the restriction evaluation activity are listed in Table 2-2. Fuel savings are calculated based on aircraft type and nominal fuel burn at different altitudes.

Table 2-2. History of Static Altitude Restriction Removal: ZID

History of Static Altitude Restriction Removal		
Restrictions Lifted or Modified	**Estimated Annual Fuel Savings**	**Estimated Annual Savings @ $1.00 per Gallon**
Apr. – Nov. 2000 – 6 restrictions	234,350	$234,350
Mar. – Apr. 2001 – 13 restrictions	770,885	770,885
Possibly Lift June 2001 – 1 restriction	23,716 (not included in total)	23,716 (not included in total)
Estimated Annual Savings	**935,235**	**$935,235**

ZID has suspended further meetings with the airlines until after the installation of URET CCLD. The sites are currently preparing for the transition to the new system.

2.5 Future Benefits Work

The expansion of URET to seven contiguous sites provides opportunities for more extensive benefit work. In addition to the lifting of altitude restrictions, the opportunity will now exist for reduction in specified routes. Controllers will be more likely to grant longer and increased frequency of directs, across centers. Receiving controllers in the new URET centers will have a 20-minute look-ahead of incoming traffic.

There is also an effort under way to review the preferred routes that are flown between city pairs and through large blocks of airspace that do not correspond to any single facility boundary. Some of these routes are circuitous causing additional flying time and distance. CAASD is assisting the FFPO in analyzing these routes to determine if more direct routings can be granted with URET CCLD in operation. The methodology being developed to evaluate the routes has parallels with the methodology used to evaluate static altitude restrictions:

- Identify possible candidates that are burdensome to airlines
- Coordinate with the sites for their review and decision-making
- Work with the sites to develop a process for testing the routes, evaluating them, and determining if they can be modified or removed.

3.0 PASSIVE FINAL APPROACH SPACING TOOL (pFAST)

The pFAST implementation for Los Angeles (LAX) at the Southern California TRACON (SCT) has improved situational awareness, thereby slightly reducing missed arrival slots and near-in TRACON holding. This section describes the operational use of pFAST at SCT/LAX, outlines the analyses used, and presents some preliminary results.

3.1 Description

The Passive Final Approach Spacing Tool (pFAST) component of the Center TRACON Automation System (CTAS) assists controllers and air traffic managers in managing the arrival flow in terminal airspace.

3.2 Operational Use at LAX

As the installation and adaptation of pFAST progressed at SCT in the LAX area, it became apparent that operations were different from those for which pFAST was designed, and significant changes to the program code would have to be made in order for the original implementation to work effectively. However, the facility personnel determined that they could achieve improvements in situational awareness without the tool providing suggested runway assignments and sequence numbers. This interim implementation uses auxiliary displays to provide controllers at key positions with a broader view that encompasses traffic from outside the TRACON airspace, all the way to the runway.

A TRACON uses short-range radar equipment to provide air traffic services. This radar equipment has a range of about 55 nmi, which encompasses an adequate area for controlling traffic around an airport. It has the advantage of higher resolution and more frequent updates than longer-range radar, and this ability is necessary because of the higher congestion traffic that occurs near busy airports. The enroute centers (ARTCCs) use longer-range radar since they control traffic over much larger areas.

Data is supplied to pFAST from both the TRACON short-range radar equipment and from the ARTCC long-range equipment. Therefore, pFAST is designed to "look" at all of the inbound traffic to an airport from distances well outside of TRACON airspace. It also looks at the traffic coming from all directions around the airport. An individual TRACON controller working a specific sector is usually not equipped to see beyond the TRACON airspace, or even to look at other sectors within this airspace in much detail.

Typically, the TRACON divides airspace into "feeder" and "final" sectors. The feeder sectors provide a smooth flow of traffic from busy arrival routes toward the final sectors, which subsequently provide an efficient flow to the arrival runways. Each of these sectors controls a relatively small amount of airspace. To work effectively, the controllers need to set their radar display to show much less than the full range of the radar equipment. They do this to avoid screen clutter, which occurs when many aircraft are operating in relatively little space. If there is screen clutter, a controller begins to have difficulty differentiating one aircraft from another because targets and data blocks begin to overlap. All of this results in an individual controller having little or no information on what is happening in other sectors.

As originally designed, a pFAST installation supplies suggested runway assignments and sequence numbers for arrival aircraft to the controllers. It also has plan view (P-GUI) and timeline view (T-GUI) displays that are normally installed in the Traffic Management Unit for planning purposes. Because pFAST gets information from the ARTCC long-range radar, as well as the TRACON short-range radar, these supplemental displays can convey the "big picture" of the traffic situation better than other traditional displays. Further, these displays show the current data block information regardless of which sector controller may be entering or updating the data. In the LAX area of SCT, this additional information is given to the two LAX final controller positions and the two primary LAX feeder sectors, through additional displays installed at those operating positions.

While the SCT pFAST installation is not yet capable of providing suggested runway assignments and sequence numbers, it does provide benefit by giving controllers additional information in the form of a bigger picture of the overall traffic situation. This allows the controller to better fit the traffic that s/he is working into an overall efficient operation.

As an example of how this works, let us assume that a feeder sector controller is working a steady stream of busy traffic toward a final sector. Using the pFAST display, the controller can see airplanes heading toward the same final sector from sectors not under her control. This added information allows the feeder sector controller an opportunity to create gaps in the arrival stream, so that the final controller will have places to put these other aircraft. The feeder controller may also see opportunities to feed traffic into runways that have smaller loads, thereby creating needed gaps and lessening the delay created at busier runways. This also allows for arrival runway balancing which increases overall airport efficiency. The increase in situational awareness provided by the new displays allows controllers to recognize more opportunities for improvements in efficiency, and better take advantage of these opportunities through easier coordination.

3.3 Translating pFAST Metrics into User Benefits

The pFAST evaluation at each of the FFP1 Core Capability Limited Deployment (CCLD) sites focuses on safety, capacity improvement, and efficiency of user operations. Safety is discussed in Section 1.0 of this report. FFP1 capacity metrics for pFAST seek to address the following issue: *Does pFAST increase peak-period throughput at airports where it is implemented?* We anticipate that the increased situational awareness provided by the pFAST displays will help TRACON controllers land more airplanes in a given period of time for given airport and weather conditions. Thus our primary pFAST capacity metric is:

- Difference between actual arrival rate and reported Airport Acceptance Rate (AAR)

Efficiency metrics for pFAST seek to address the following issues:

- *Does pFAST impact flight times and flight distances for traffic arriving at airports where it is implemented?*
- *Does pFAST redistribute delay from lower to higher, more fuel efficient altitudes for*

arriving aircraft at airports where it is implemented?

By increasing situational awareness for final and feeder controllers, pFAST may reduce flight times and distances by reducing holding or vectoring inside TRACON airspace. The pFAST efficiency metrics therefore attempt to determine whether overall flight time from the point where pFAST first detects an arriving aircraft to the runway threshold has changed. Since flight time is significantly impacted by wind speed and direction, we also look at distance flown in the same area, as this metric is less affected by wind.

Use of pFAST might also redistribute delay from the lower altitudes to the higher altitudes of the controlled airspace. This would be advantageous to aircraft operators, since aircraft typically burn less fuel per unit of time when flying fast at high altitudes than when "low and slow." Thus even with no change in total delay, any redistribution of delay should be measured.

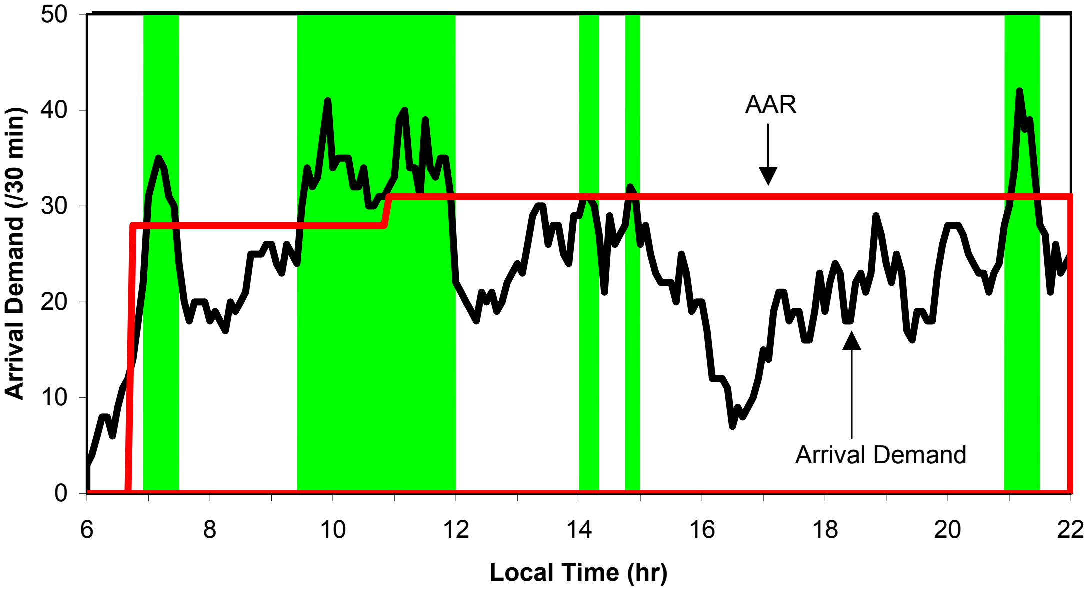
For this preliminary analysis at LAX, the pFAST efficiency metrics are:

- Flight time and distance from the 200 nmi to the 106 nmi range ring
- Flight time and distance from the 106 nmi to the 50 nmi range ring
- Flight time and distance from the 50 nmi to the 24 nmi range ring
- Flight time and distance from the 24 nmi range ring to the runway threshold.

3.4 Analysis and Results: SCT/LAX

Our analysis of pFAST at SCT/LAX is in its early stages. Initial Daily Use (IDU) started in February 2001 and pFAST is expected to achieve Planned Capability Available (PCA) status in August 2001. Weather, log data, and arrival rates were available through April 2001. Track data was available through March 2001. We therefore, only have three months of arrival data since IDU and two months of track data with which to draw conclusions. The results that follow should be considered preliminary, and will likely change as controllers and managers become more familiar with the tool and we obtain more data.

Unlike some of the other CTAS sites (MSP, DFW, DIA), LAX is not a major hub, and therefore does not have clearly defined peaks that occur each day. (Compare sample arrival rate graph in Figure 3-1 with arrival traffic at MSP Figure 4-4.) As mentioned in the previous section, operators anticipate the most benefit from situational awareness provided by pFAST during periods when the airport is under "stress". In order to determine the stressed periods, we compared the Arrival Demand to the reported AAR. For this analysis, we defined Arrival Demand as the maximum of the estimated arrival rate (calculated from ETMS filed flight times) or the actual arrival rate (from TRACON data). Those times for which the Arrival Demand was greater than the AAR are the stressed periods. This represents a rather strict measure of stress that can be considered a lower bound on the amount of time the airport is under pressure. Figure 3-1 shows the Arrival Demand and the AAR. Shaded sections indicate periods when the Arrival Demand was greater than the AAR. Since this analysis relies heavily on the AAR, we do not consider times when the AAR was not recorded (e.g. the time before 6:45 am in Figure 3-1.)



Shaded areas indicate Arrival Demand > AAR.

Figure 3-1. Example of Arrival Demand and AAR at LAX

During the time period from December 2000 through April 2001, the Arrival Demand was greater than the AAR approximately 3 out of the busiest 16 hours per day on average (or about 18 percent of the time). Before December, this percentage amounted to 11 percent of the same hours. Because of this change in demand, we show results comparing the initial use data (February 2001 – April 2001) with the period of similar demand (December 2000 – January 2001) as well as with all the available pre-pFAST data (February 2000 – January 2001).

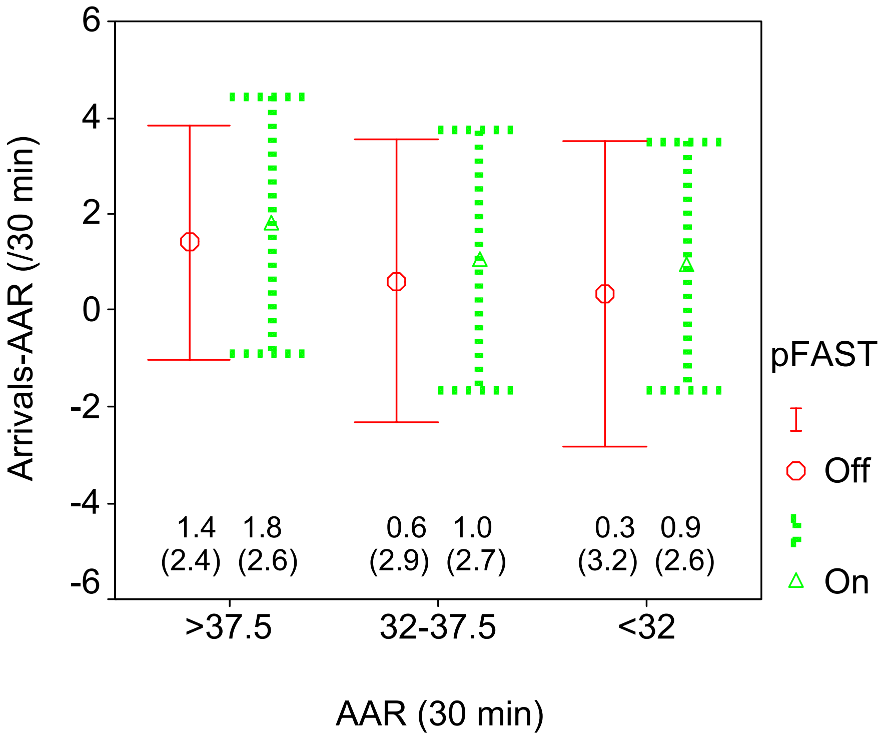
The results of some of our preliminary analyses of the impact of pFAST at LAX are summarized below. More details regarding each of these preliminary results follow.

- The difference between the actual arrival rate and the AAR increased slightly, and the standard deviation of this difference decreased. Both results are beneficial and statistically significant to the 5 percent level.
- The average flight distances and flight times from the 200 nmi range ring to the runway threshold both exhibited a slight but statistically significant (again to the 5 percent level) decrease.
- The standard deviation of both the flight distances and flight times decreased significantly, indicating increased predictability.
- A redistribution in the flight times and flight distances occurred, such that times and distances closer to the runway decreased while those farther from the runway increased or stayed the same, thereby increasing fuel efficiency

3.4.1 Difference between Actual Rate and Acceptance Rate

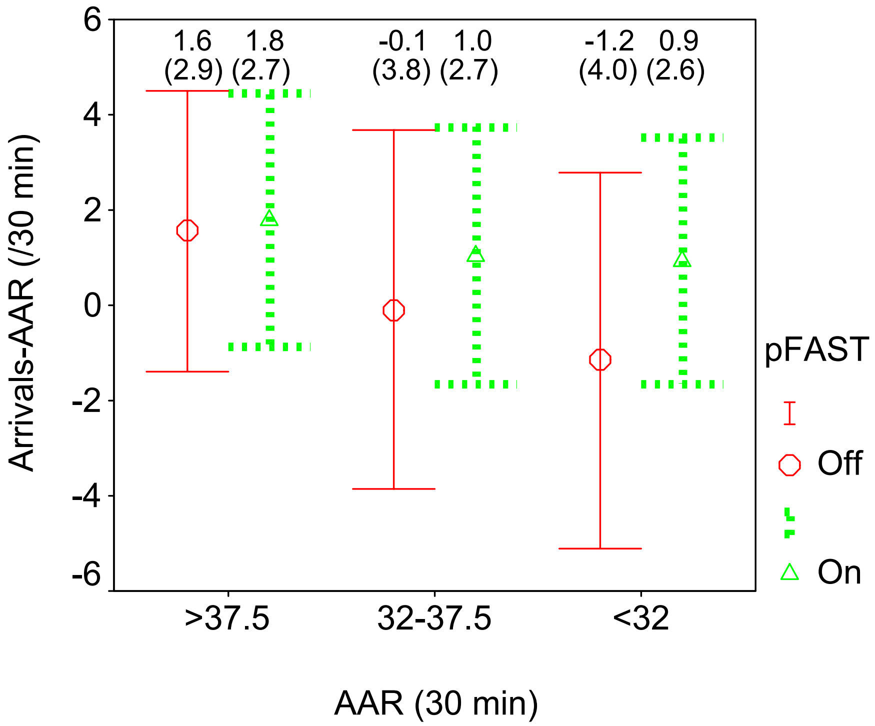
In order to correct for airport conditions and weather, we decided to probe throughput at LAX by examining the difference between the actual arrival rate and the logged AAR for pre and post pFAST implementation. We further subdivided the results by AAR to display the effectiveness of pFAST for differing weather and airport conditions. The AAR subdivisions correspond to the optimum and reduced rates found in the FAA Airport Capacity Benchmark Report (Reference 1).

As mentioned in the previous section, a significant change in the demand suggested comparing the initial use data with two different baseline sets. Figure 3-2 shows the mean plus or minus one standard deviation for the actual arrival rate less the AAR per 30 minutes from February 2000 through April of 2001, while Figure 3-3 shows the same graph for the period that had similar demand (December 2000 through April of 2001). The annotations within each graph designate the value of the mean. In both cases, the actual number of arrivals compared to the called arrival rate was higher after pFAST implementation, and this result was slightly more pronounced for lower AARs. In addition, the standard deviation after implementation was lower suggesting a more predictable flow.



Actual Arrivals-AAR per 30 minutes subdivided by AAR and comparing before and after the pFAST IDU date for 2/1/00 – 4/30/00. Annotation designates mean value and (standard deviation).

Figure 3-2. Arrival-Acceptance Rate by AAR: All Data

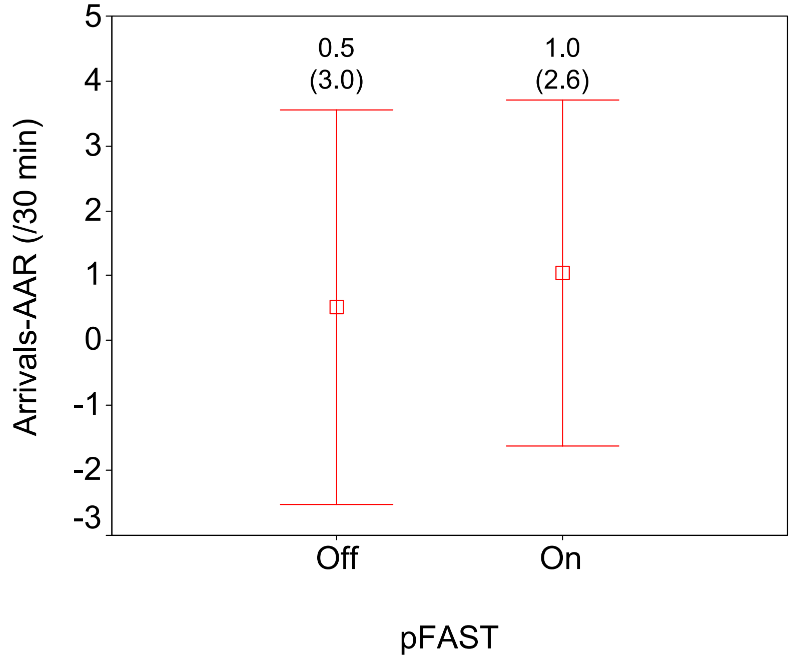


Actual Arrivals-AAR per 30 minutes subdivided by AAR and comparing before and after the pFAST IDU date for 12/1/00 – 4/30/00. Annotation designates mean value and (standard deviation).

Figure 3-3. Arrival-Acceptance Rate by AAR: Equal Demand Period

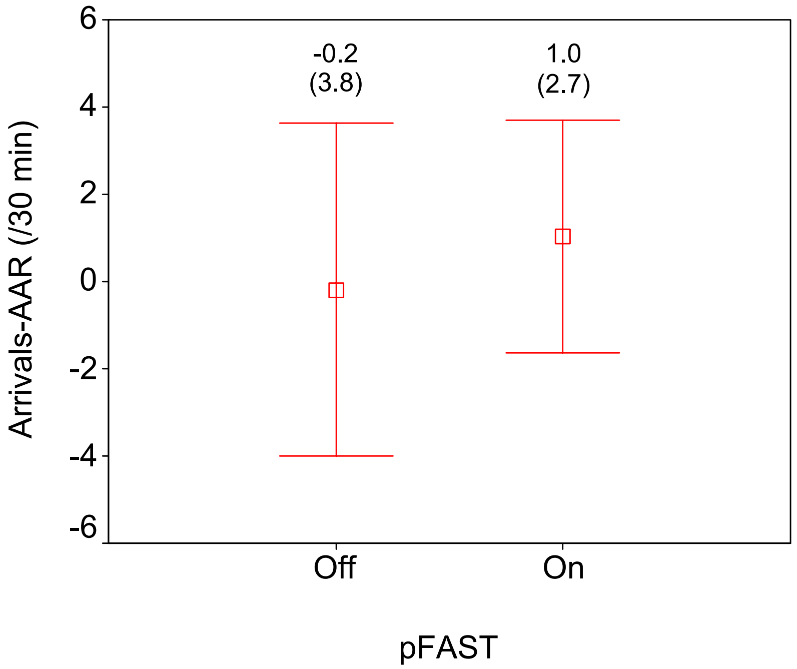
In order to determine the mean benefit for all AARs, it is necessary to weight the results to reflect the historical AAR distribution. This weighting results in an average increase of one airplane per hour (or 0.5 in 30 minutes see Figure 3-4) using all the data and an increase of 2.4 airplanes an hour (or 1.2 per 30 minutes see Figure 3-5) using the data that has similar demand. Both of these results are statistically significant to the 5 percent level. The standard deviation also decreases in each case suggesting an increase in predictability.

Using the two data sets as a range, the results show an increase of between 1 and 2.4 arrivals per hour during the times when the airport is stressed. This amounts to an increase of arrivals during stressed periods between 1.5 and 3.5 percent.



Actual Arrivals-AAR per 30 minutes weighted by AAR comparing before and after the pFAST IDU date for 2/1/00 – 4/30/00. Annotation designates mean value and (standard deviation).

Figure 3-4. Weighted Comparison of Arrival and Acceptance Rate: All Data

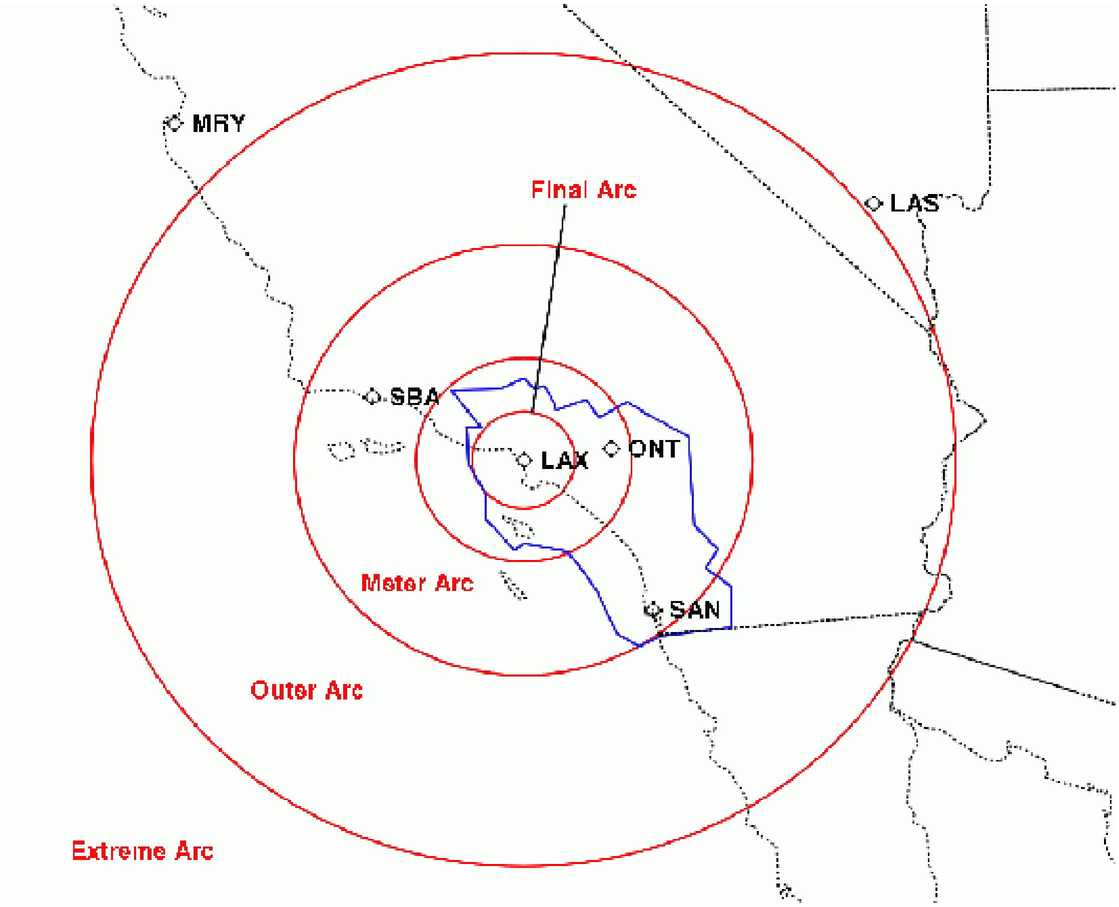


Actual Arrivals-AAR per 30 minutes weighted by AAR comparing before and after the pFAST IDU date for 12/1/00 – 4/30/00. Annotation designates mean value and (standard deviation).

Figure 3-5. Weighted Comparison of Arrival and Acceptance Rate: Equal Demand Period

3.4.2 Flight Times and Distances

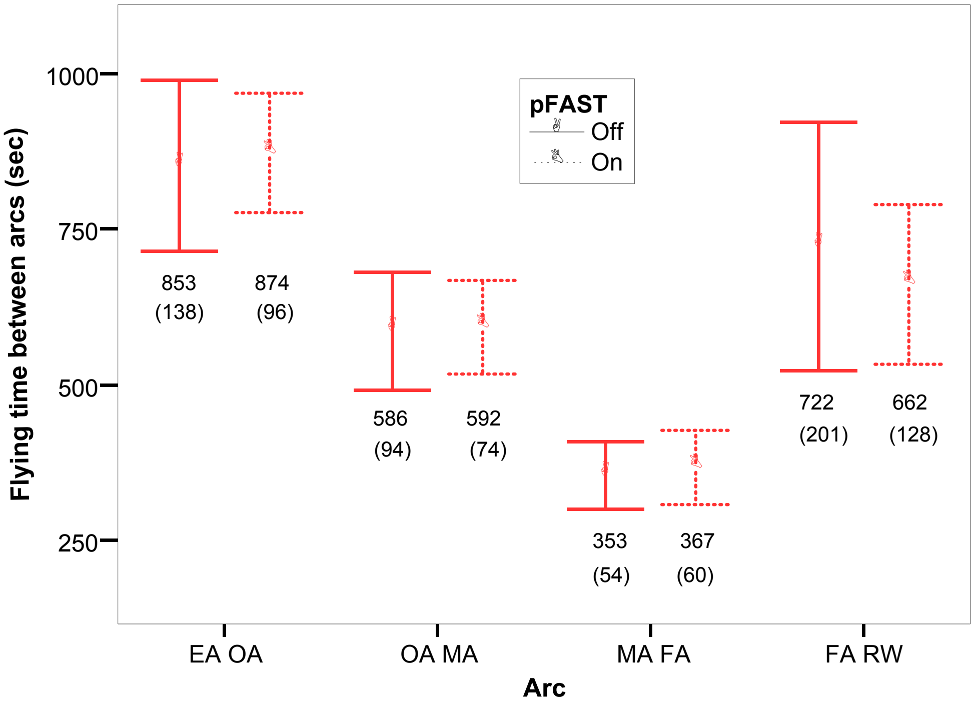
As part of the analysis of pFAST, we analyzed track data to determine arrival aircraft flight times and flight distances in SCT airspace. The flight path of arriving aircraft is divided into range rings centered on LAX. The predefined rings are: the Extreme Arc (EA) at 200 nmi, the Outer Arc (OA) at 106 nmi, the Meter Arc (MA) at 50 nmi, and the Final Arc (FA) at 24 nmi. Figure 3-6 shows a simple map of Southern California with the outline of SCT, as well as the placement of the rings and the location of some area airports. Host data allowed for calculation of the average flying times and flying distances between each successive pair of rings for planes that landed during stressed periods at LAX. Since the Host data does not generally have a complete list of arrivals, the demand issue discussed in the previous section was not of concern for this data, and therefore, the results make use of all available data. We did, however, limit the consideration of flight times and distances to those for which the airport was in the standard configuration (over 90 percent of the time). Addition of the other configurations sometimes used at LAX introduces unnecessary error in the times and distances flown.



Outline of SCT airspace and arcs used for flight time and distance analysis centered on LAX.

Figure 3-6. LAX Range Rings for Flight Time and Distance Metrics

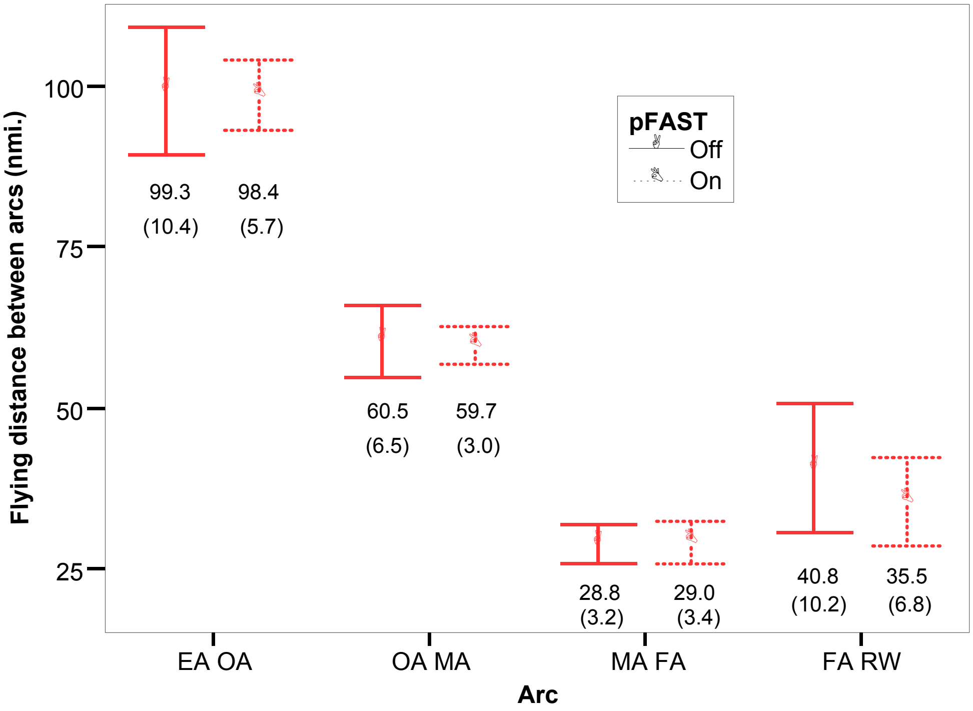
Figure 3-7 displays the mean flying time between rings plus or minus one standard deviation. There are three interesting features of this graph. First, the sum of the average flying times decreases by 19 seconds between the Extreme Arc and the Runway Threshold (RW) after pFAST implementation. More interesting, the redistribution of the flying times after implementation shifts, such that the average time between the Final Arc and the runway decreases by roughly a minute, while the flying time between the other rings increases. This is interesting because a shift in delay away from the airport to higher altitudes is more fuel efficient if the overall delay stays constant. Also, reduced flying times close-in may suggest that less holding occurs close to the airport. A reduction in close-in holding allows controllers to maintain focus on the arrival stream and deliver more efficient flows of aircraft to the runway. Lastly, the standard deviation of the flying times between each set of arcs decreases, indicating increased predictability.



Compares before and after the pFAST IDU date for 12/1/00 – 4/31/00. Annotation designates mean value and (standard deviation).

Figure 3-7. Flight Time between Arcs during Busy Periods

Since the wind may affect flying times, examination of the flying distances is also necessary to accurately measure holding in terminal airspace. Figure 3-8 shows the mean flying distances between the rings plus or minus one standard deviation. In this graph, the total average distance flown from the Extreme Arc to the runway decreases 6.8 nmi after pFAST implementation. Most of this decrease occurs between the Final Arc and the runway, where the average distance drops during stressed periods by roughly 5 nmi. The distance between the Meter Arc and the Final Arc increases slightly, supporting the argument that holding has been pushed farther from the airport, and the distance between the further arcs decreases by a very slight amount. The standard deviation of the flying distance decreases by a substantial amount in each arc, again suggesting increased predictability.



Compares before and after the pFAST IDU date for 12/1/00 – 4/31/00. Annotation designates mean value and (standard deviation).

Figure 3-8. Flight Distance between Arcs during Busy Periods

Table 3-1. summarizes the flight times and flight distances data in terms of savings after pFAST implementation. Positive values indicate a decrease in time or distance, while negative values point to an increase in these values. The last column displays a sum of the savings showing a net decrease of time and distance from the extreme arc to the runway. All of these findings are significant to the 5 percent level.

Table 3-1. pFAST Flight Time and Flight Distance Savings

	EA/OA	OA/MA	MA/FA	FA/runway	Total
Time(sec)	-21	-6	-14	60	19
Distance (nmi)	0.9	0.8	-0.2	5.3	6.8

3.4.3 Alternative Analysis of Delay

Delay is subject to changes in demand and weather that are independent of ATC performance. For this reason, we generally focus on operational throughput measures to gauge the impact of FFP1 tools. However, the National Center of Excellence for Aviation Operations Research (NEXTOR), working as part of the FFP1 Metrics Team, developed a methodology for estimating delay changes with normalization for demand and weather, that we can compare with the metrics outlined in the previous sections. A description of the methodology and some preliminary results follow.

Given the higher throughput rates observed during periods of high demand at LAX after pFAST was implemented (see section 3.4.1), it is reasonable to expect that arrival delays at LAX decreased. A simple way to understand the relationship between capacity and delay is through a deterministic queuing diagram. Figure 3-9 is an example of such a diagram. The curve A(t) plots cumulative arrival demand at an airport over the course of a day. Thus, by the time $t_{a,i}$ a total of N_i flights would have arrived in the absence of any capacity constraint. The curve D(t) is a cumulative curve of the number of flights that have actually arrived (in the literature this is termed the "departure curve"). The arrival capacity of the airport sets an upper bound to the slope of the D(t) curve. Before t_0 and after t_1 the two curves overlap, implying that the airport has sufficient capacity to serve all demand without any queuing. Between these times however, the curves diverge because capacity is insufficient. During this period, there are delays. For example, the N_ith flight cannot actually arrive until time $t_{d,i}$. If the airport operates on the first-in/first-out principle, so that the N_ith flight on the A(t) curve is the same as the N_ith flight on the D(t) curve, then the time interval $t_{d,i}$-$t_{a,i}$ is the queuing delay to the N_ith flight. Regardless of whether this principle holds, the total queuing delay is the area between the two curves—the shaded region in Figure 3-9.

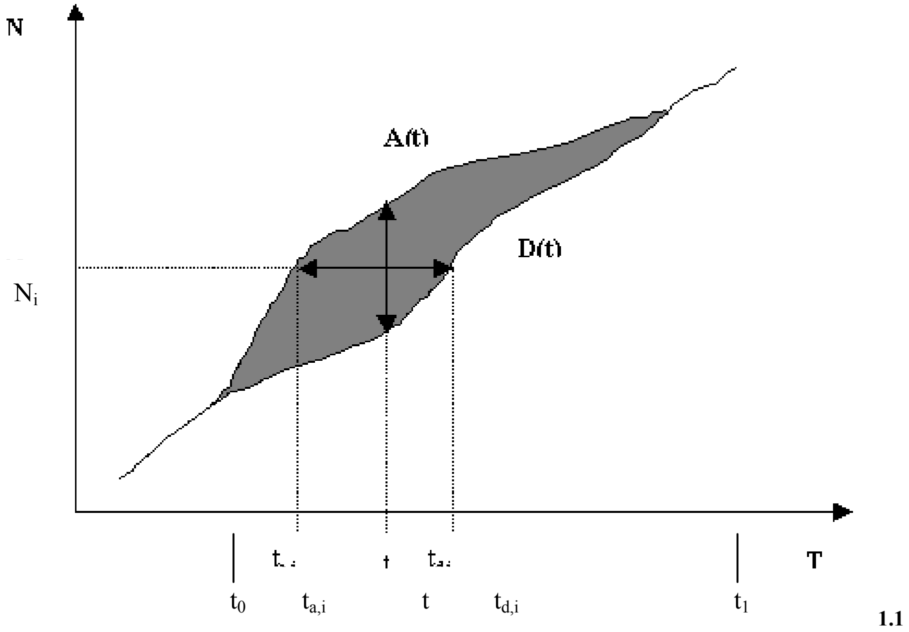


Figure 3-9. Hypothetical Arrival and Departure Curves at an Airport

To apply this model we must construct both the A(t) and the D(t) curves. For A(t), we use the OAG 15-minute flight counts available from the ASPM Airport Efficiency data base. We based D(t) on the 15-minute Arrival Acceptance Rate (AAR) values available from the same source. Results for two sample days are depicted in Figures 3-10 and 3-11. In the first case, LAX was operating under visual flight rules, with the AAR at 84 per hour for most of the day. The two curves virtually overlap, with an average queuing delay of just 1 minute per flight. Figure 3-11 shows a bad day, with AARs in the mid-60s for most of the time as a result of limited visibility. The average queuing delay on this day is 24 minutes per flight. Average arrival delays for the days, calculated from the ASPM Individual Flights data, were 4.5 and 35.7 minutes respectively.

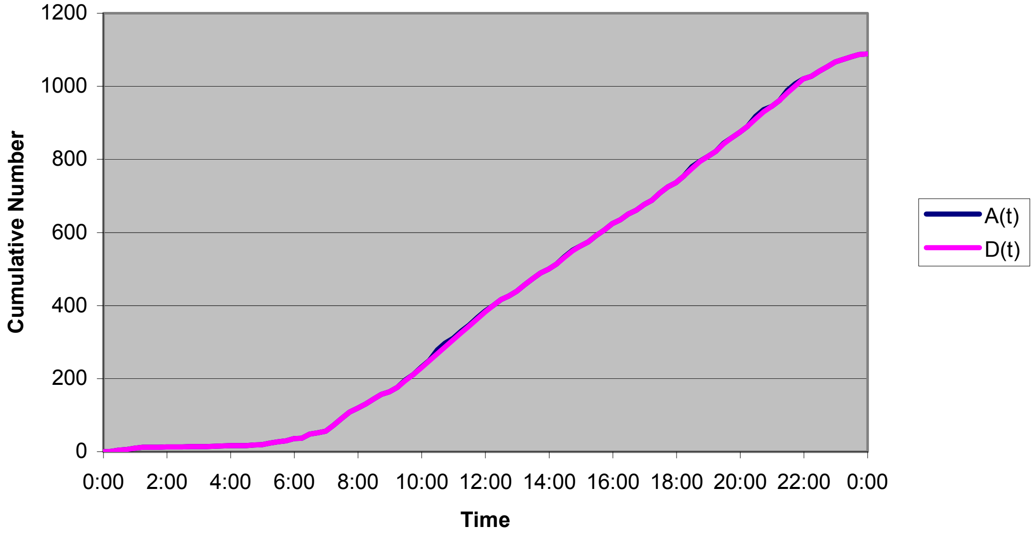


Figure 3-10. Queuing Diagram for 11/7/00

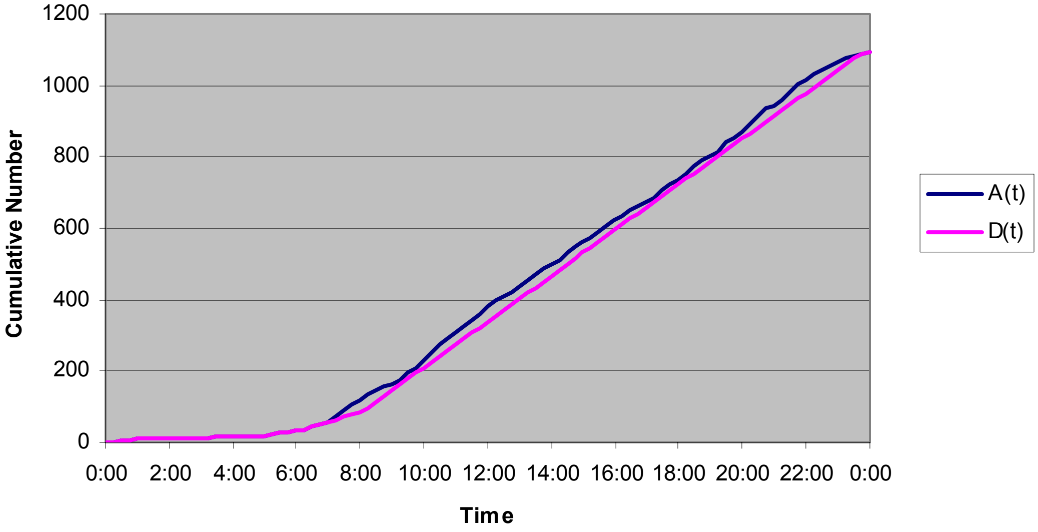


Figure 3-11. Queuing Diagram for 12/1/00

In general, the average queuing delay is correlated with, and of a similar magnitude to, the observed average delay. This is shown in Figure 3-12, which plots average queuing delay against average arrival delay at LAX for every day between November 2000 and April 2001. The correlation between the two delays is 0.68. The linear trend line reveals a positive intercept at around 8 minutes. This implies that, even in the absence of queuing, the average flight arrives 8 minutes late. Sources of this additional delay include congestion at the origin airport, mechanical problems, and taxiway congestion at LAX.

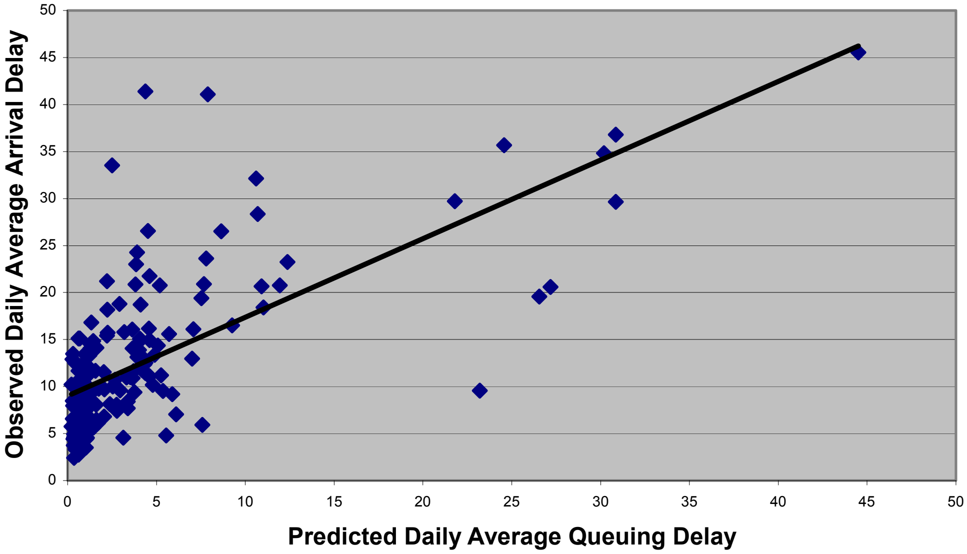


Figure 3-12. Observed vs Predicted Delays

A way of estimating the effect of pFAST on delay is by comparing observed delays before and after regular use of the tool began (on February 9, 2001). In this approach, we use predicted queuing delay as a normalization variable, estimating a model of the form: $AD_t = \alpha + \beta PQD_t + \gamma PFAST_t$, when AD_t is average arrival delay on day t, PQD_t is predicted queuing delay on day t, and $PFAST_t$ is a dummy variable set to 1 for days on or after February 9, 2001, and 0 for all days prior to that date. When this model is estimated for all days in the time period from November, 2000 to May, 2001, we find that the parameter γ has an estimated value of -1.63 ± 0.77 minutes. This estimate is statistically significant at the 0.05 level, and implies that if we compare two days with equal predicted queuing delays before and after pFAST implementation, the latter is expected to have an average arrival delay 1.63 minutes less than the former. This result is comparable to the capacity increase described in previous sections.

4.0 TRAFFIC MANAGEMENT ADVISOR (TMA)

TMA at Minneapolis Center continues to assist contollers with smoothed arrival flows into the TRACON, thereby improving use of TRACON airspace and peak operations at the airport. This section updates previous reports on ZMP/MSP and presents preliminary findings at ZDV/DIA. Both analysis techniques and results are described.

4.1 Description

The Traffic Management Advisor (TMA) component of CTAS assists controllers in the enroute cruise and transition airspace around major airports by providing them with a means of optimizing arrival throughput. By optimizing throughput, TMA helps to reduce arrival delays, and the resulting uniformity of arrival flows can also lead to an increase in departure rates and decreased departure delays. Inputs to the TMA system include real-time radar track data, flight plan data, and a three-dimensional grid of wind speeds and directions. TMA's trajectory models use this information, updated every 12 seconds, to compute routes and optimal schedules to the TRACON meter fixes for all arriving IFR aircraft, with consideration given to separation, airspace, and airport constraints.

TMA is used both as a strategic planning tool by managers in the ARTCC Traffic Management Unit (TMU) and tactically by controllers who are actively controlling aircraft. The TMA computer interface incorporates two primary strategic displays. The Timeline Graphical User Interface (T-GUI) displays estimated time of arrival, CTAS-computed delay, scheduled time of arrival, and runway assignment for each track in the TMA area of regard. The Planview Graphical User Interface (P-GUI) displays a planview depiction of arriving aircraft. TMU managers use these and other displays to determine if and when metering will need to be imposed in the Center's airspace so that the arrival rate specified by the TRACON is not exceeded. When metering is imposed, floor controllers see a sequence list overlaid on their radar displays that indicates which aircraft need to be delayed and by how much.

4.2 Operational Use at ZMP/MSP; ZDV/DIA

TMA is currently in use at Ft. Worth, Minneapolis, and Denver Centers for Dallas/Ft. Worth, Minneapolis/St. Paul, and Denver arriving traffic, respectively. TMA was initially implemented at Ft. Worth Center prior to the establishment of the Free Flight Phase 1 program, concurrent with the redesign of Dallas/Ft. Worth terminal airspace, so no applicable baseline data is available for this site. The impact of TMA at Dallas/Ft. Worth has been discussed in the June 2000 metrics report (Reference 2), and no further analysis of this site is envisioned. This report will update the preliminary analysis of TMA at Minneapolis Center that was presented in the December 2000 report (Reference 3), and introduce a discussion of Denver Center.

Metering, or TMA usage, times are being collected and analyzed for all TMA locations as the systems are deployed. Figure 4-1 and 4-2 present total monthly metering times for Denver International (DIA) and Minneapolis/St. Paul (MSP) Airports, respectively.

At DIA, metering times have increased from September to February 2000, where they reached a peak of approximately 1,075 minutes. However, in November 2000, no metering took place at DIA. In the three months following February 2001, total metering times have decreased, averaging approximately 265 minutes per month. Although metering is employed at Denver, airport capacity is such that the facility does not require it on a regular basis. The Metrics Team expects that future metering times will increase as demand increases.

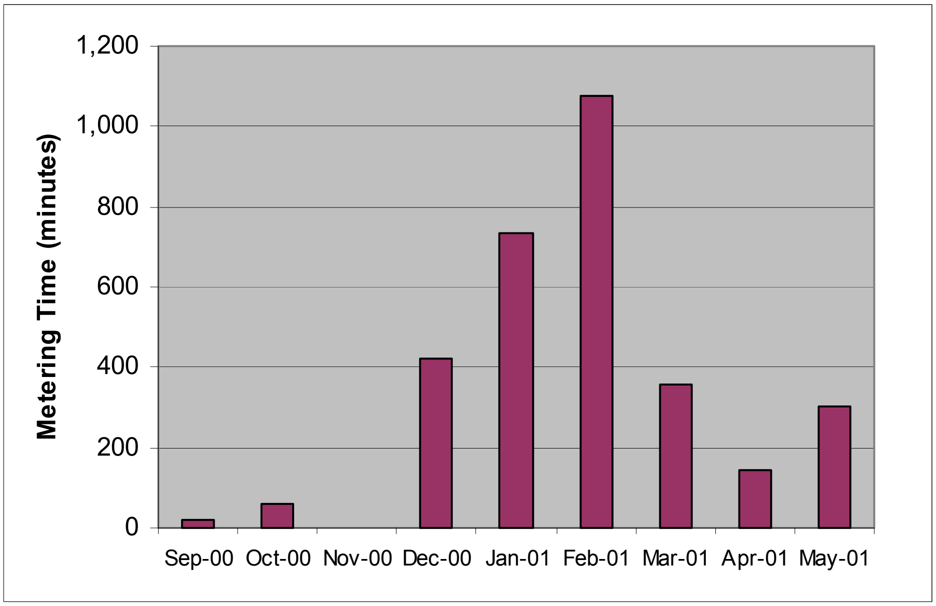


Figure 4-1. ZDV/DIA Total Monthly Metering Times

Figure 4-2 presents TMA metering times for MSP. This chart shows that the amount of time spent metering at MSP is considerably higher than that of DIA. This suggests that MSP experiences significantly more times, possibly with longer durations, of capacity constraints. Although the total metering times vary substantially by month, the overall trend of the dataset from August 2000 to May 2001 does not suggest that total monthly metering times at MSP have significantly increased.

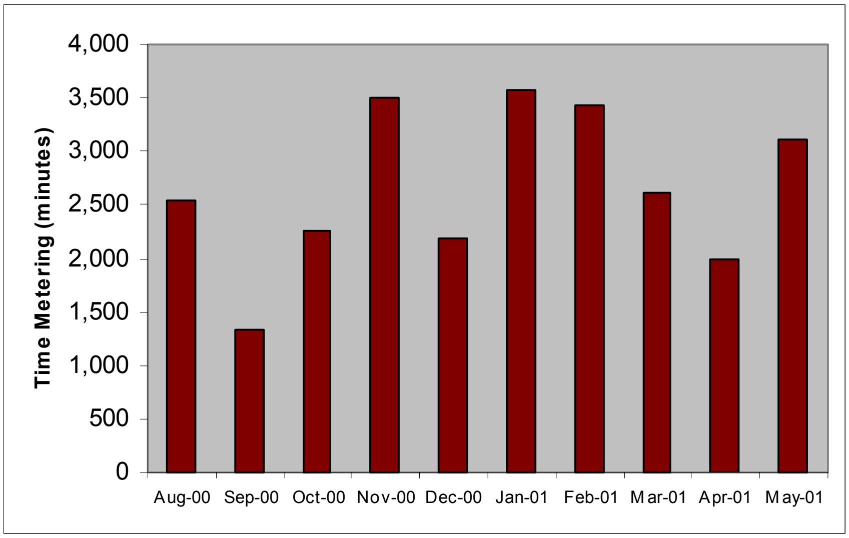


Figure 4-2. ZMP/MSP Total Monthly Metering Times

4.3 Translating TMA Metrics into User Benefits

The FFP1 performance metrics were originally developed in 1999 in concert with Free Flight stakeholders (as represented by RTCA Inc.), and are documented in Reference 4. Since that time, some modifications have been made to these metrics as more experience was gained with the FFP1 implementation. (For a detailed discussion of these modifications see Reference 3).

The TMA evaluation at each of the FFP1 Core Capability Limited Deployment (CCLD) sites focuses on safety, capacity improvement, and efficiency of user operations. Safety has already been discussed in Section 1.0 of this report. FFP1 capacity metrics for TMA seek to address the following issue: *Does TMA increase peak-period throughput at airports where it is implemented?* We anticipate that by smoothing the flow of arriving traffic during arrival peaks, and by more predictably matching the arrival rate specified by the TRACON, TMA metering will help TRACON controllers to land more airplanes in a given period of time. It is also possible that by making arrival flows more predictable, TMA will help TRACON and tower controllers to depart more aircraft during arrival peaks. Thus our primary TMA capacity metrics are:

- Airport Acceptance Rate (AAR)
- Actual peak-period arrival rate
- Actual peak-period operations rate (arrivals plus departures)
- Difference between AAR and actual arrival rate

Efficiency metrics for TMA seek to address the following issues:

- *Does TMA impact flight times for traffic arriving at airports where it is implemented?*
- *Does TMA redistribute delay from lower to higher, more fuel efficient altitudes for*

arriving aircraft at airports where it is implemented?

By helping ARTCC controllers to meter arriving traffic, TMA may reduce the flight time for those flights by reducing holding or vectoring outside of TRACON airspace. On the other hand, it is possible that arrival rates to the TRACON are increased, but that landing rates cannot be increased, so that final approach segments need to be increased and additional delays are obtained within the TRACON. The TMA efficiency metrics therefore attempt to determine whether overall flight time from the point where TMA first detects an arriving aircraft (200 nm from the arrival airport or at the Center boundary, whichever is closer) to the runway threshold have changed.

Use of TMA might also redistribute delay from the lower altitudes of the TRACON to the higher altitudes of Center airspace. This would be advantageous to aircraft operators, since aircraft typically burn less fuel per unit of time when flying fast at high altitudes than when "low and slow." Thus even with no change in total delay, any redistribution of delay between the TRACON and Center should be measured.

For this preliminary analysis the TMA efficiency metrics are:

- Flight time from the 200 nmi to the 160 nmi range ring
- Flight time from the 160 nmi to the 100 nmi range ring
- Flight time from the 100 nmi to the 40 nmi range ring
- Flight time from the 40 nmi range ring to the runway threshold.

In order to see if TMA has had any positive or negative downstream impacts at the airport (resulting from increased operations rates), we have also examined taxi times. Thus, we have included the following additional efficiency metrics:

- Taxi-in time
- Taxi-out time.

4.4 Analysis and Results: ZMP/MSP

4.4.1 Summary of Results To Date

We can detect no statistically significant change in acceptance rates at MSP since TMA adoption. We have nonetheless observed an *increase* in actual arrival rates of about one arrival per hour during peak periods. We believe that this increase in arrival rates results from the smoother flow of traffic being delivered to the TRACON with TMA. There has been a corresponding increase in the difference between actual arrival rates and acceptance rates of about 1.5 arrivals per hour during peak periods, and a *decrease* in the standard deviation of the difference between the actual arrival rate and the acceptance rate of about 1.5 arrivals per hour. Thus there appears to be less variation in the actual arrival rate during peak periods with TMA.

The peak operations rate (the sum of the arrival rate and departure rate) has also *increased* by about three operations per hour. We suspect that the smoother arrival flows at MSP during peak periods have allowed tower and TRACON controllers to depart more aircraft during these periods. There has been a small *decrease* in flying times in Center airspace (200 nmi from the airport to the meter fix) for arriving flights during arrival peaks, and a small *increase* in taxi times for both arriving and departing flights.

In summary, we have thus far observed the following at MSP:

- an increase in actual arrival rates and operations rates during arrival peaks
- no net change in transit times for arrivals
- a small increase in average taxi times (approximately 20 seconds) for departures.

4.4.2 Airport Acceptance Rate

When examining the impact of a change in automation or procedures at an ATC facility, we typically begin by examining the rates that the facility is specifying to see if any change has occurred; for TMA at MSP, this means the Airport Acceptance Rate (AAR). We examined AARs at MSP from 1 October 1999 through 30 April 2001 in order to see if the TRACON has increased rates since TMA was implemented.[1] TMA became operational at ZMP/MSP in late June 2000, but we have elected to exclude data from 15 June 2000 to 15 July 2000 from this (and all subsequent) analyses because of uncertainties concerning the status of the system during that time period. The data for these analyses were obtained from facility logs, which were reviewed each day. AAR changes were entered in the FFP1 operational performance database.

Figure 4-3 presents the weighted average AAR at MSP, pre- and post-TMA implementation, segmented into visual and instrument approach conditions (as specified in the logs).[2] Each observation was weighted by the length of time over which the particular log entry applied. Over the period in question there was a very slight increase in AARs under both visual and instrument conditions.

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[1] While we have data prior to 1 October 1999, there was taxiway construction activity at the airport prior to this date. Consequently AARs were lower at that time.

[2] Observations equal to or greater than 80 were excluded. These observations were considered to be unreasonably large, and only comprise 0.3 percent of the overall sample.

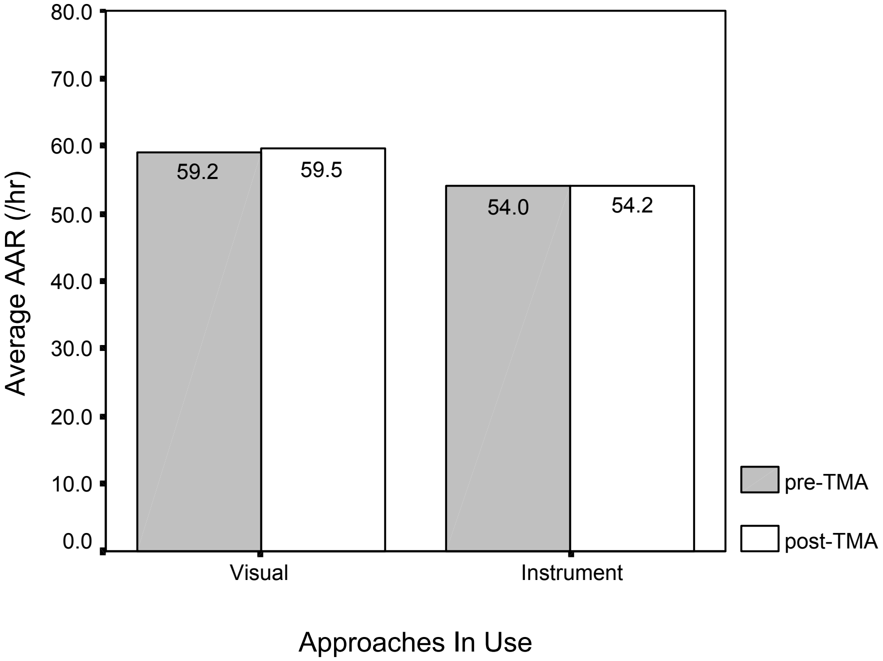

Figure 4-3. Acceptance Rate Comparison of Means

To see if the above differences in mean acceptance rates are statistically significant, we conducted a two-way analysis of variance of AAR, with TMA use and approach type as the independent factors. Again, the dependent variable (AAR) was weighted by the duration of the log entry. The results of this analysis, presented in Table 4-1, indicate that the TMA and interaction effects are *not* statistically significant (as indicated by the small *F* statistics and correspondingly large significance factors). Thus we must conclude that there has not been a statistically significant change in acceptance rates at MSP since TMA implementation.

Table 4-1. AAR Analysis of Variance

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1710777353	1	1710777353	267182.7	.000
TMA	12302	1	12302	1.9	.166
IFR	3645923	1	3645923	569.4	.000
Interaction	321	1	321	.050	.823
Error	17256148	2695	6403		
Total	1949098672	2699			

4.4.3 Actual Arrival Rate

Next, we examined the actual arrival rate during arrival peaks at MSP. Figure 4-4 illustrates a typical day at MSP. There are six distinct arrival peaks during the day resulting from Northwest Airlines hub scheduling practices, and one or two somewhat less distinct peaks between 19:30 and 20:30 local time. Figure 4-5 illustrates an entire month of arrival rates. The dark areas in the figure indicate periods of few arrivals, while the light areas indicate periods of intense activity. It is apparent from this figure that the first five peaks of the day are fairly consistent, but that after this the operation is less predictable, perhaps because of delays early in the day eventually taking their toll on the hub operation.

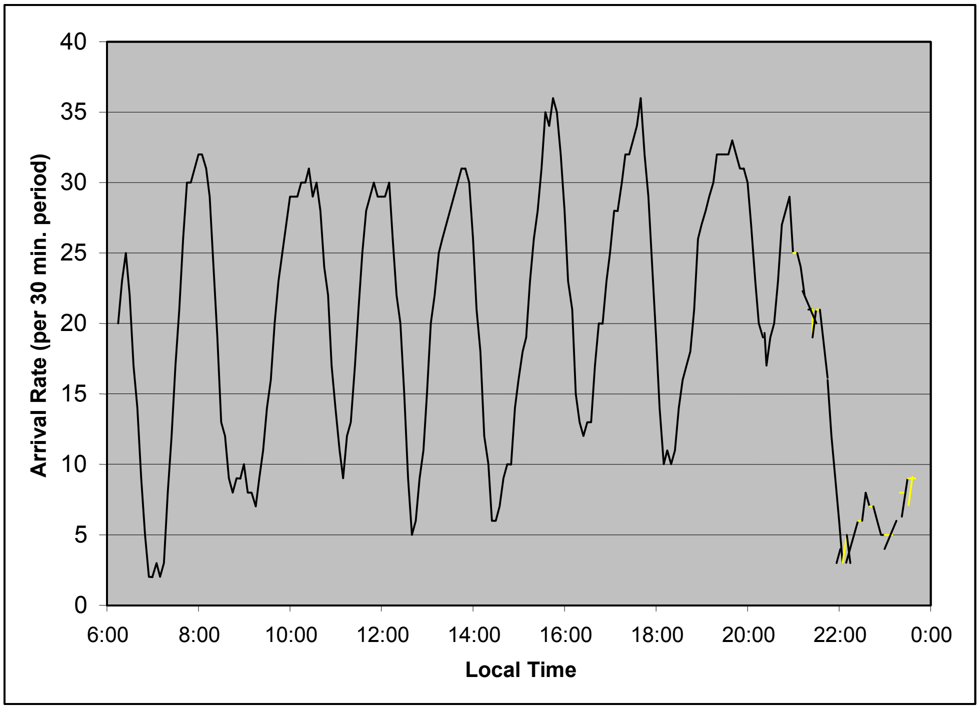

Figure 4-4. MSP Arrival Rate, 3 November 2000

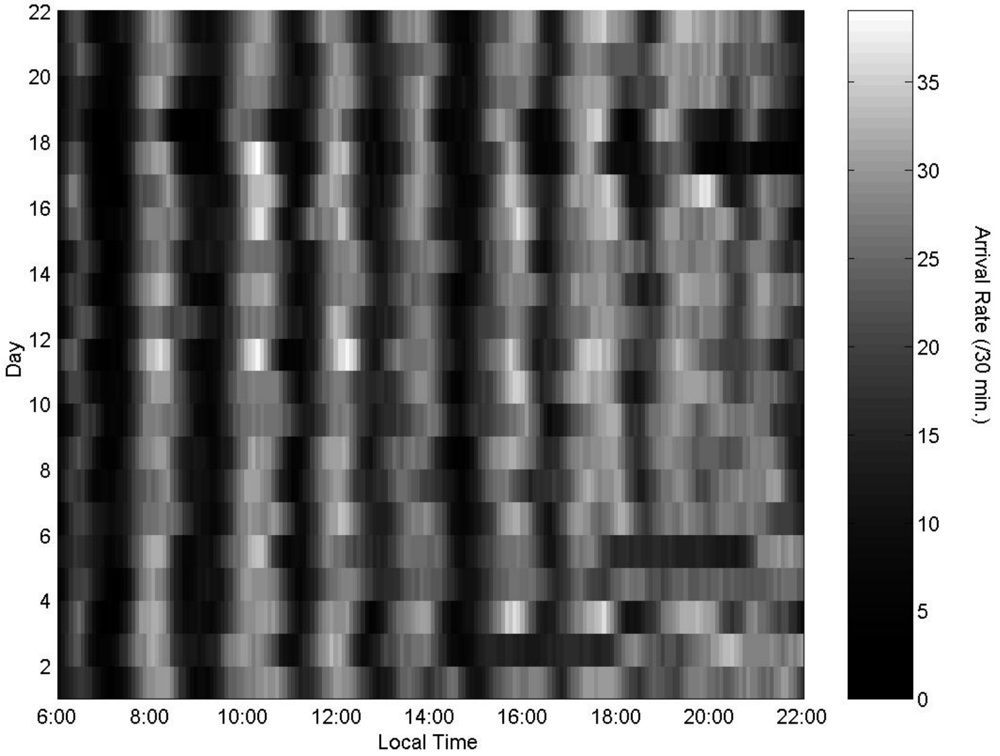

Figure 4-5. MSP Weekday Arrival Rates, November 2000

We use an algorithm to isolate peaks from arrival data of the type illustrated in Figures 4-4 and 4-5. This algorithm identifies the closest-spaced 30 aircraft during periods of at least 30 minutes when the arrival rate is greater than the day's average arrival rate. These 30 aircraft typically land within a 28 minute period. We then compute an equivalent hourly arrival rate for this period of time. The hourly arrival rate, or "Peak 30 Rate," then becomes one observation for subsequent statistical analyses.

Figure 4-6 presents the mean peak arrival rates before and after TMA implementation at ZMP, for both visual and instrument approaches. The same time period used for the AAR analysis was also used here, namely 1 October 1999 through 30 April 2001, providing 3,918 observations. This simple comparison of means suggests that peak arrival rates are slightly higher since TMA introduction, with a somewhat larger increase when instrument approaches are being conducted. As expected, arrival rates overall are lower under instrument approach conditions.

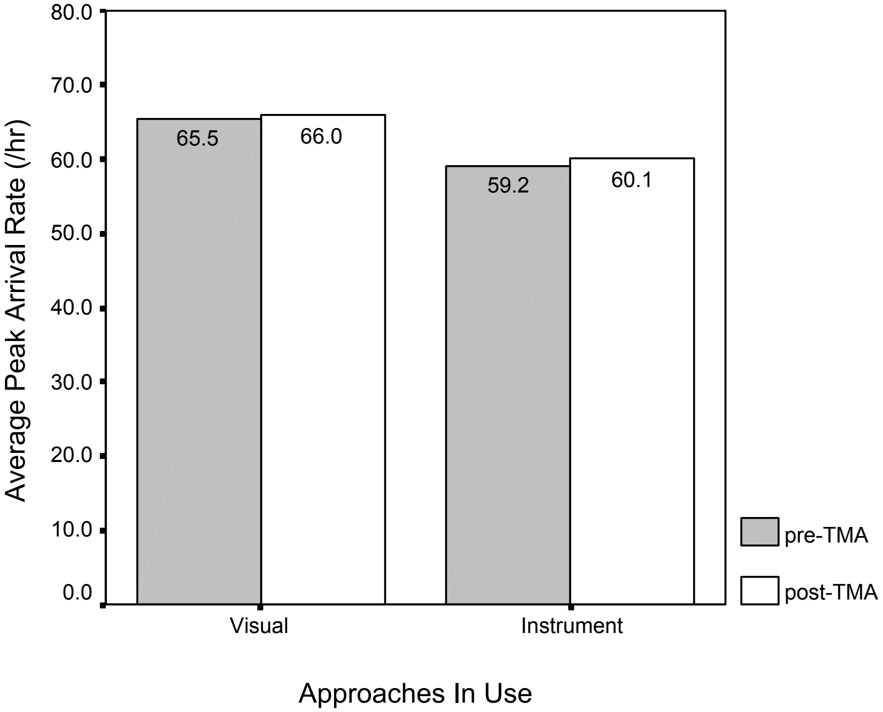

Figure 4-6. Actual Arrival Rate Comparison of Means

In order to test if the above differences in the mean rates are significant, a two-way analysis of variance of the peak arrival rate, with TMA and instrument approaches as the independent variables, was conducted. The results of this analysis are presented in Table 4-2. The analysis of variance suggests that TMA has had a statistically significant impact on actual arrival rates, independent of the type of approach in use (as indicated by the large *F* statistic and correspondingly small significance value for the TMA variable). This analysis provides no indication of an interaction between TMA and the type of approach in use.

Table 4-2. Actual Arrival Rate Analysis of Variance

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	13695575	1	13695575	217164	.000
TMA	464	1	464	7.36	.007
IFR	31976	1	31976	507	.000
Interaction	43	1	43	.687	.407
Error	245829	3898	63		
Total	16023891	3902			

We next performed a regression analysis of the peak arrival rate, in which we were able to include several variables relating to airport conditions, weather, and airline schedule in addition to TMA usage and the type of approaches in use. For this analysis we included data back to 23 July 1999, the beginning of our data set, since we could explicitly account for the completion of construction at the airport at the end of September 1999 with a dummy variable (this variable ended up being insignificant and was ultimately removed from the model).

The independent variables included in the regression analysis are as follows:

TMA	TMA usage dummy variable 0 = pre-TMA deployment 1 = post-TMA deployment
WEEKDAY	day of week dummy variables
SAT	
P30DEPS	number of departures during arrival peak
Two_Parallels	two parallel runway dummy variable 0 = no or one parallel in operation 1 = two parallels in operation
CROSSING	crossing runway dummy variable 0 = runway 12/30 not in use 1 = runway 12/30 in use
IFR	instrument approaches dummy variable 0 = visual approaches 1 = instrument approaches
VIS	$\log_{10}$ of surface visibility in statute miles
log(ModCeiling)	$\log_{10}$ of reported ceiling in feet (zero ceiling replaced with 10 ft., unlimited replaced with 30,000 ft.)
VWIND	surface wind velocity in knots
SN	snow dummy variable 0 = SN not in surface weather report 1 = SN in surface weather report
FZ	“freeze” dummy variable 0 = FZ not in surface weather report 1 = FZ in surface weather report
RA	rain dummy variable 0 = RA not in surface weather report 1 = RA in surface weather report

SPRING	season dummy variables
SUMMER	
FALL	
BANKn	daily arrival bank dummy variables (n = 2 thru 8)

The season and bank variables are included here to try to account for airline schedule (different aircraft arrive in each bank, and the schedule changes with the seasons). All of the independent variables in this regression model were found to be significant. Various other variables were tried, but were not found to be significant. For example, a dummy variable for thunderstorm activity in the surface weather report was no significant. An interaction term between TMA and the instrument approaches variable was also not found to be significant.

The results of this regression are presented in Table 4-3. The overall regression is statistically significant, as suggested by the large value of the F statistic. Nevertheless, the goodness-of-fit statistics (R^2, adjusted R^2) are relatively low, suggesting about half of the variation of the dependent variable is not explained by the model. The coefficients of the model all have the expected signs. For example, the snow, rain, and “freeze” variables all have negative signs, as we would expect. The visibility and ceiling variables both have positive signs, since increases in these variables should lead to increased arrival rates. The TMA variable has a positive coefficient of 1.082. Thus when weather, airport conditions, and demand (albeit crudely) are taken into account, TMA appears to increase arrival rates by about one aircraft per hour during arrival peaks.

Table 4-3. Actual Arrival Rate Regression Results

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.707	.499	.497	5.842

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	148361	23	6450.48	189.0	.000
Residual	148792	4360	34.13		
Total	297153	4383			

Coefficients

Term	Unstandardized Coef.		Standardized Coef.	t	Sig.
	B	Std. Error	Beta		
(Constant)	58.553	1.270		46.093	.000
TMA	1.082	.187	.066	5.787	.000
WEEKDAY	2.263	.255	.124	8.868	.000
SAT	-1.308	.335	-.055	-3.910	.000
P30DEPS	-.408	.013	-.442	-32.550	.000
Two_Parallels	1.400	.695	.022	2.016	.044
CROSSING	-3.985	.393	-.124	-10.149	.000
IFR	-2.048	.255	-.119	-8.022	.000
VIS	.347	.053	.098	6.569	.000
Log(ModCeiling)	1.551	.224	.110	6.930	.000
VWIND	-.165	.021	-.091	-7.936	.000
SN	-2.537	.490	-.065	-5.173	.000
FZ	-3.640	1.679	-.024	-2.168	.030
RA	-1.278	.566	-.026	-2.256	.024
SPRING	3.609	.245	.198	14.720	.000
SUMMER	3.250	.310	.144	10.491	.000
FALL	3.153	.244	.173	12.915	.000
BANK2	1.467	.356	.061	4.117	.000
BANK3	1.329	.345	.055	3.857	.000
BANK4	.949	.362	.039	2.620	.009
BANK5	-4.596	.356	-.187	-12.917	.000
BANK6	2.991	.342	.126	8.748	.000
BANK7	2.358	.348	.096	6.771	.000
BANK8	-1.892	.429	-.057	-4.412	.000

4.4.4 Difference between Actual Rate and Acceptance Rate

TMA is used by Center controllers to help meter arrival flows into TRACON airspace. All else being equal, we would expect to see a “smoother” flow of traffic into the TRACON when TMA is used to meter than when its predecessor ASP was used, or when no tool was used. In addition, we would expect to see the actual arrival rate more closely match the rate specified by the TRACON (i.e., the AAR).

In order to see if this is the case, we examined the difference between actual arrival rates and AARs during arrival peaks. Each observation consists of the actual arrival rate computed for the closest-spaced 30 aircraft (the same as before) *less* the AAR specified for that time period. We used ZMP logs to determine when the Center was actually metering traffic. The times logged were manually matched with the 30-aircraft peak periods, and those which closely corresponded were judged to have been metered. Currently, the Center does not log every occurrence of metering, so while we are able to identify peaks when metering is performed, we cannot tell with any certainty when metering is *not* being performed. Therefore we have only used peaks from prior to TMA IDU for the non-metering sample, and those peaks that we can conclude were metered subsequent to IDU for the metering sample. Metering data were only available through 31 March 2001.

The results of the initial comparison of the difference between actual and specified arrival rates is presented in box plot form in Figure 4-7 (for a description of the box plot, see Appendix A). Two points should be obvious from this figure: first, that the median of the difference between actual arrival rate and AAR is higher when TMA is used to meter traffic; and second, that the standard deviation of this difference is smaller when TMA metering is used (5.70 arrivals/hour when metering, 7.29 arrivals/hour when not metering). A statistical test on the difference between these two medians confirms that the difference is statistically significant at the 5 percent level (Reference 5). Additionally, a squared-ranks test on the difference between the observed variances of the two samples similarly confirms that the difference is statistically significant at the 5 percent level (Reference 5). The finding that the difference between actual and specified rates is higher with TMA metering than without is consistent with the results reported above, namely that AARs have not appreciably changed but that actual arrival rates have increased. For this to be true the difference between actual rates and AAR must have increased.

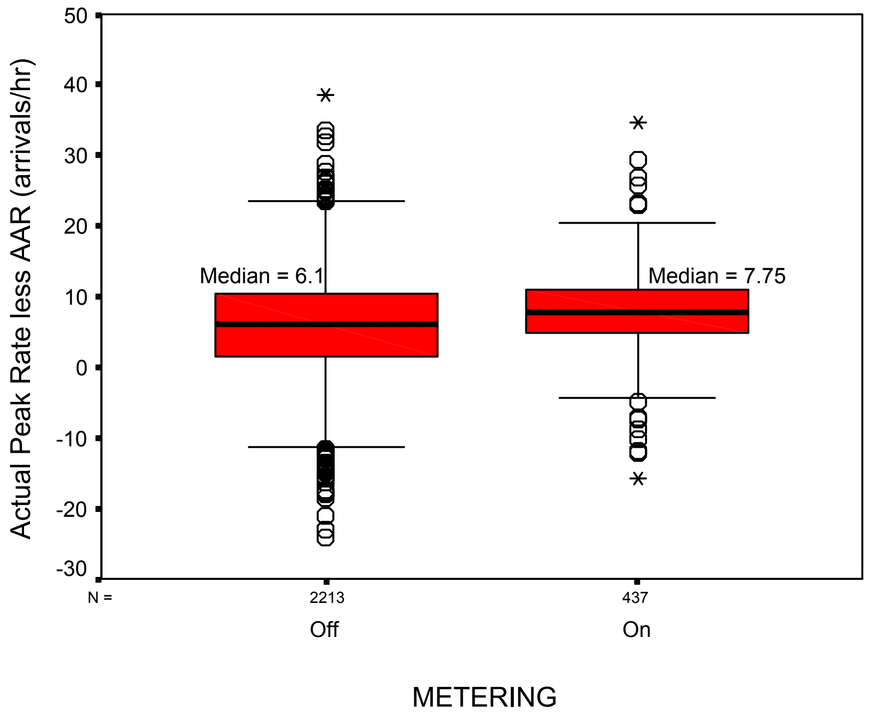

Figure 4-7. Comparison of Actual Arrival Rate and AAR

4.4.5 Operations Rate

We also examined the potential impact of TMA on total operations at MSP during arrival peaks. It has been suggested that the use of TMA smoothes the arrival flow to such an extent that the tower is able to increase the number of departures during arrival rushes (arrivals and departures share the same runways at MSP). In order to test this, we summed the arrival rate examined above with the departure rate achieved at the same time to obtain an operations rate.

Figure 4-8 presents the mean peak-period operations rates at MSP from 1 October 1999 through 30 April 2001. As can be seen, there has been what appears to be a significant increase in the operations rate under both visual and instrument conditions. To test if this observed increase is indeed statistically significant, we again performed a two-way analysis of variance on this data set. Table 4-4 exhibits the results of this analysis. The TMA factor is highly significant in this analysis, and the interaction term between TMA and the approach variable (IFR) is not, as was the case for the actual arrival rate ANOVA.

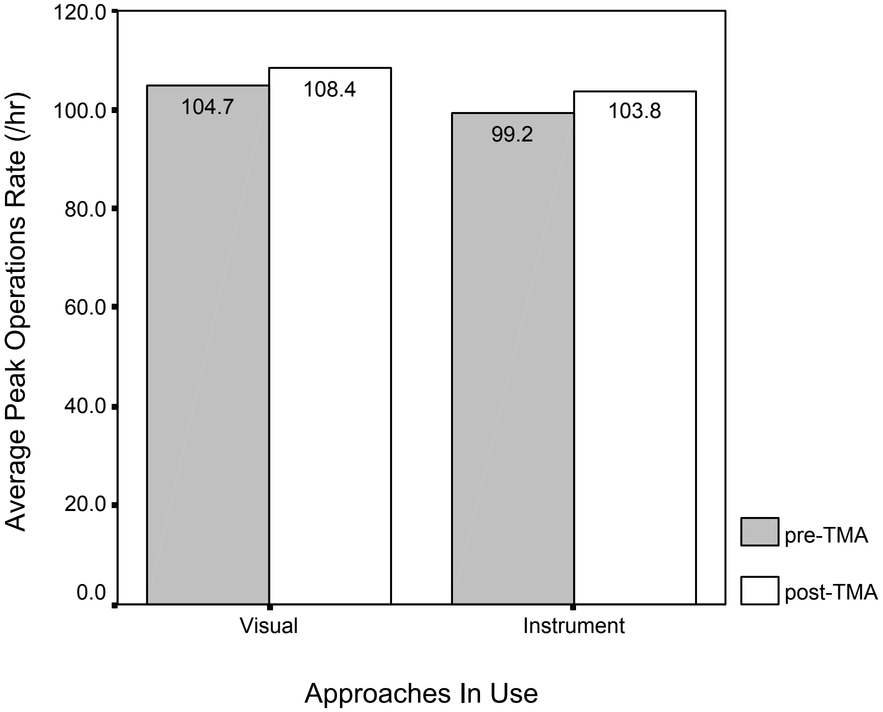

Figure 4-8. Operations Rate Comparison of Means

Table 4-4. Operations Rate Analysis of Variance

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	37729173	1	37729173	132599	.000
TMA	14737	1	14737	51.7	.000
IFR	22389	1	22389	78.7	.000
Interaction	141	1	141	.496	.481
Error	1109116	3898	285		
Total	44110239	3902			

Finally, we conducted another regression analysis, using the peak-period operations rate as the dependent variable, and similar independent variables as were used for the actual arrival rate regression analysis. The results of this analysis are presented in Table 4-5. The overall model is highly significant (as indicated by the large *F* statistic), although the fit is poor (thus the predictive properties of this model should be poor). All of the independent variables included in the model are significant at the five percent level. The TMA dummy variable has a positive coefficient of 3.0. Based on the results of this model, we may conclude that TMA has resulted in an increase of about three operations per hour during arrival peaks at MSP.

Table 4-5. Operations Rate Regression Model

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.592	.350	.347	13.785

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	447137	20	22357	117.7	.000
Residual	829088	4363	190.0		
Total	1276226	4383			

Coefficients

Term	Unstandardized Coef.		Standardized Coef.	t	Sig.
	B	Std. Error	Beta		
(Constant)	86.773	2.847		30.484	.000
TMA	3.044	.440	.089	6.915	.000
WEEKDAY	2.457	.602	.065	4.084	.000
SAT	-2.165	.789	-.044	-2.743	.006
SPRING	5.432	.577	.144	9.421	.000
SUMMER	8.327	.728	.178	11.443	.000
FALL	4.802	.573	.127	8.381	.000
BANK2	-10.383	.806	-.207	-12.885	.000
BANK3	6.623	.807	.132	8.204	.000
BANK4	13.109	.813	.260	16.129	.000
BANK5	-14.939	.823	-.294	-18.159	.000
BANK6	5.327	.805	.108	6.616	.000
BANK7	2.617	.820	.051	3.193	.001
BANK8	5.902	.992	.087	5.947	.000
IFR	-1.783	.581	-.050	-3.068	.002
Two_Parallels	5.490	1.638	.041	3.352	.001
CROSSING	-4.710	.925	-.071	-5.090	.000
SN	-2.773	1.091	-.034	-2.543	.011
RA	-5.007	1.315	-.048	-3.808	.000
VWIND	-.221	.048	-.059	-4.613	.000
Log(ModCeiling)	1.962	.500	.067	3.926	.000

4.4.6 Flight Times

As part of the analysis of the effects of TMA at MSP we analyzed arrival aircraft flight times in Minneapolis Center (ZMP) airspace. TMA is used to meter aircraft according to AAR being called by the TRACON. If issuing delay to the arriving aircraft is necessary, it is most economical to incur delay (i.e., speed control or vectoring) at higher altitudes where aircraft are more fuel efficient.

To conduct our analyses, the center airspace through which arriving aircraft must fly was divided into segments associated with a set of imaginary arcs centered at MSP (see Figure 4-9). The predefined arcs are as follows: Extreme Arc (EA) at 200 nmi, Outer Arc (OA) at 160 nmi, Inner Arc (IA) at 100 nmi, and Meter Arc (MA) at 40 nmi. Host data was used to calculate the average flying time across each of these arcs for those flights that arrived during 30-minute peak periods each day from 1 October 1999 through 31 March 2001.[3]

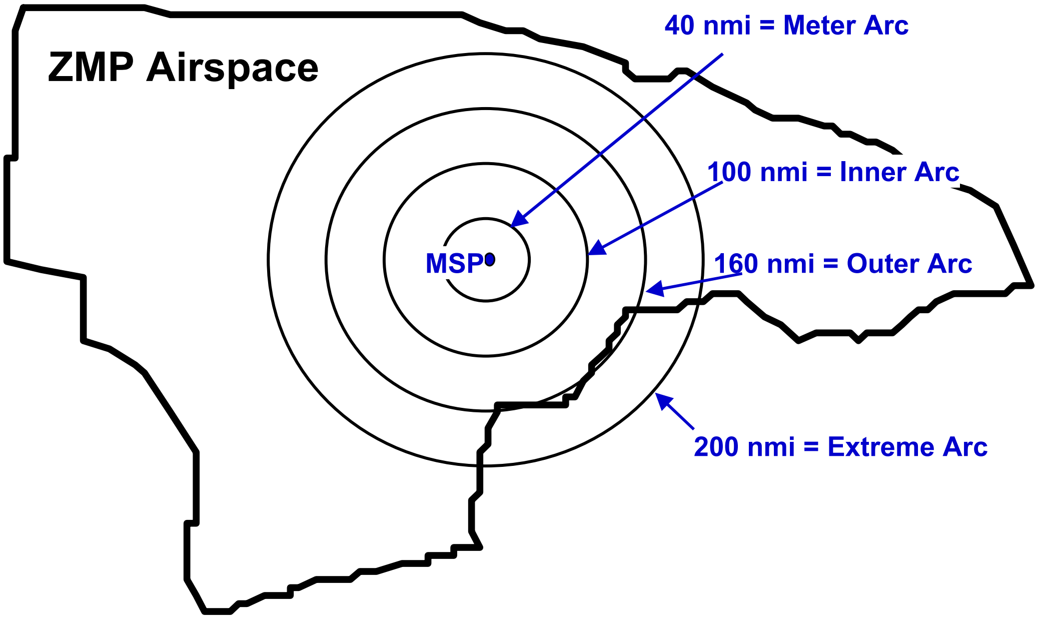

Figure 4-9. MSP Range Rings for Flight Time Metrics

TMA was deployed at MSP for Initial Daily Use on June 21, 2000. When comparing pre-TMA deployment to post-TMA deployment in a multiple regression model, the analysis shows minimal reductions in flight times attributable to TMA. Those reductions, in seconds, appear in Table 4-6. The separate savings for each arc do not add up to the EA/runway savings because there are different numbers of planes in each data set. For example, the recorded track for some flights may not start until the inner arc, while the data used for EA/runway contains only those flights whose tracks are recorded through all the rings.

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[3] For this flying time and the taxi-time analyses, each day of the data set was divided into eight distinct time spans, or “splits”, and the peak 30 minute period within each of these splits was identified as a “peak” period.

Table 4-6. TMA Flight Time Savings (sec.)

EA/OA	OA/IA	IA/MA	MA/runway	EA/runway
5	4	12	0	27

4.4.7 Taxi Times

The analysis of TMA includes a study of taxi times at MSP. Although TMA is designed to provide benefits to the flow of arrivals into MSP, it is important to understand whether there are also indirect impacts.

Airline Service Quality Performance (ASQP) data contains taxi times and was collected for both arriving and departing flights during the defined 30-minute peak arrival periods. The data for the study spans the period from 1 October 1999 to 31 March 2001 (the same period as the other analyses). ASQP data contains information on approximately 60 percent of the total flights at MSP.

Multiple regression models were developed to estimate the potential effects of TMA on taxi times. These models were developed using the same explanatory variables as the models for operations rates. The results of the models show that TMA appears to have the small but statistically significant effect of increasing taxi-out time by 0.34 minutes and increasing taxi-in time by 0.22 minutes.

These results reflect a smaller increase in taxi times than the single factor regression results shown in Figure 4-10.

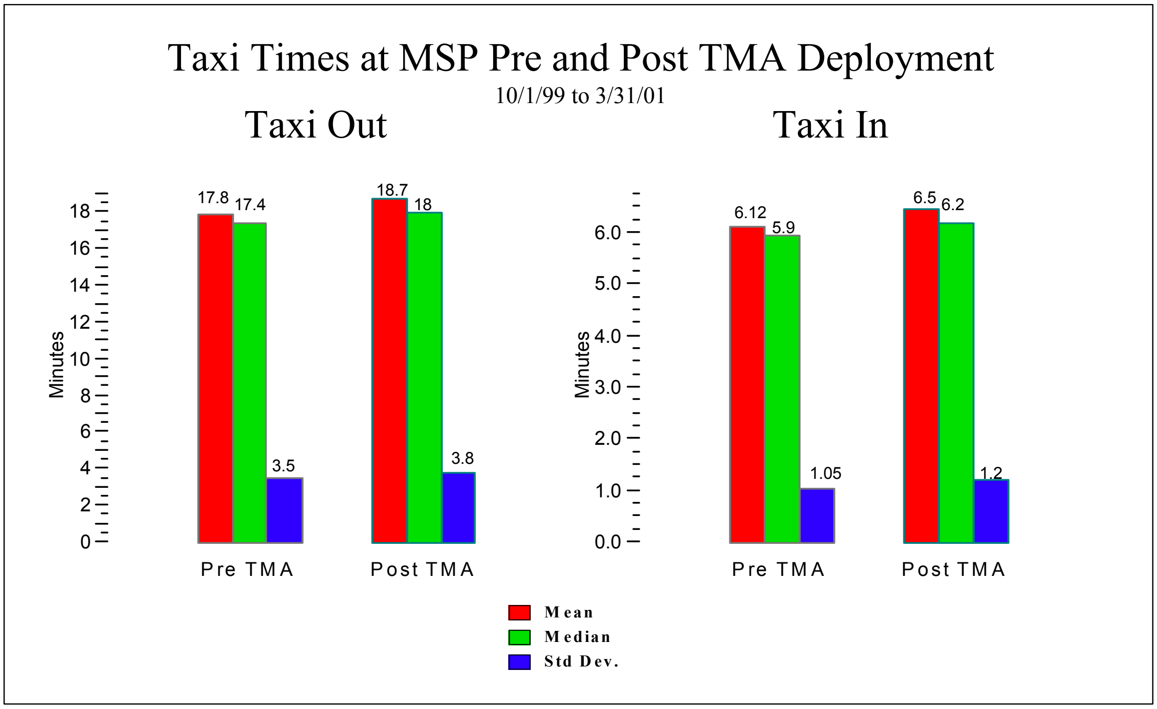


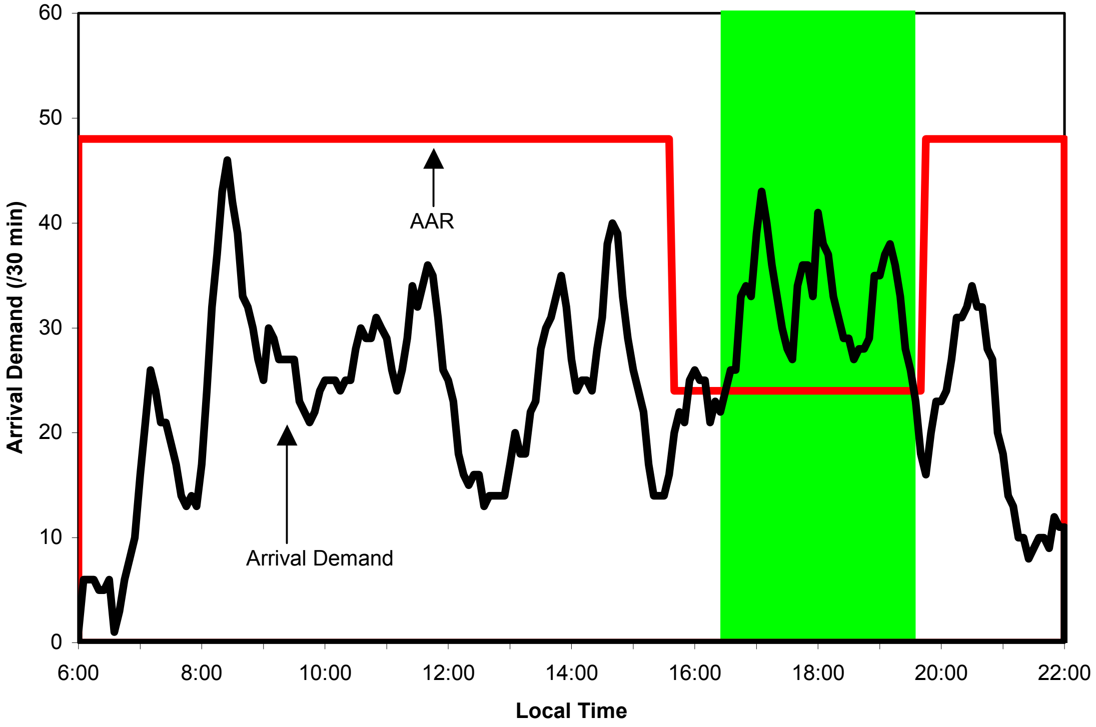
Figure 4-10. Taxi Time Statistics at MSP Pre and Post TMA Deployment

The taxi-out results shown here are similar to those reported in the December 2000 report (Reference 3). The taxi-in results shown here reflect a smaller increase than reported in the December report. Notably, at that time, the median taxi times were unchanged, indicating that some extremes in the data were responsible for the increased taxi times. Increases to taxi times could also be the result of increased operations rates.

4.5 Preliminary Analysis: ZDV/DIA

TMA has been operational at ZDV since 6 September, 2000 to meter arrivals into Denver International Airport (DIA). The Center metered 28 times from the intial date through April 2001.

Like MSP, arrivals at DIA tend to occur in regular daily peaks. Unlike MSP, these peaks tend to be shorter in duration and are not as equally spaced, making the analysis by arrival pushes somewhat more difficult. Therefore, we determined the stressed times at DIA by the same method used to analyze pFAST at SCT/LAX (see section **3.3**). This method defines an arrival demand and compares it to the logged Airport Acceptance Rate (AAR). Stressed periods are those for which the arrival demand is greater than the AAR. Figure 4-11 shows an example of arrival demand at DIA on a day when metering occurred.



Shading indicates time when Arrival Demand > AAR.

Figure 4-11. Arrival Demand and AAR at DIA during a day when metering occurred

We found that demand equals or exceeds capacity less than two percent of the time with the current demand levels at DIA. This agrees with the FAA Airport Capacity Benchmark Study (Reference 1) which states that less than 0.25% of flights are delayed significantly at DIA. Because DIA is capacity constrained so little, we have not been able to determine any statistically significant effects of TMA on actual operations rates, flight times, or flight distances. However, the total arrival demand has grown 7% at DIA since the TMA IDU date, and there is a corresponding increase in the number of stressed time periods. We continue to measure metrics at ZDV/DIA and expect to see impacts of TMA on operations as the demand continues to increase.

In April 2001 TRACON managers increased the maximum AAR during optimum conditions at DIA from 108 to 120. We believe this increase is due to a greater confidence in the operation of automation tools, an increased focus on capacity associated with FFP1, and the FAA Capacity Benchmark Study. Currently, the demand rarely reaches such a rate, but this change in acceptance rates will, in the longer term, support increased throughput during stressed periods and reduce unnecessary delay.

5.0 SURFACE MOVEMENT ADVISOR (SMA)

5.1 Description

Surface Movement Advisor (SMA) provides aircraft arrival information to Airline Operations Centers (AOCs) and/or to airline ramp towers. At those airports where SMA is implemented, ARTS III data will be available. This data provides airline operations managers with the necessary information to remain informed of the status of arriving aircraft. Similarly, ramp controllers are able to use SMA to enhance user's gate and ramp operations. In short, the availability of this system facilitates greater collaboration between tower controllers and ramp personnel and provides real-time information for decision making.

ARTS III provides real-time data on arriving aircraft that may be used to facilitate accurate prediction of future traffic flows. ARTS III data includes information on aircraft identification and position in TRACON airspace, providing the necessary information to compute estimated touchdown times. Additionally, this data can allow users to better coordinate ground support operations, allocating resources such as ramp and airport services more efficiently. As part of FFP1 SMA a display was developed by Metron Inc., which visually provides information on arriving aircraft and calculates arrival statistics including estimated time to touchdown (ETT).

5.2 Reported Anecdotal Benefits (Updated)

With the implementation of the ARTS III data feed and proof of concept display, AOC managers can now receive aircraft location and estimated touchdown times in near real-time. This improvement in situational awareness in the AOC can be relayed to the pilot enabling improved decisions when a diversion is being considered. The ARTS data feed is also valuable to airline ramp tower operators in efficient management of gates.

Based on the ability of the AOC and ramp tower personnel to observe near real time location of aircraft in the terminal domain, operational improvements have been demonstrated at SMA locations. Since the release of the December 2000 report, St. Louis, Minneapolis and Atlanta have added the ARTS III data feed. Along with the existing sites including Philadelphia, Detroit, Dallas/Fort Worth, Chicago, and New York TRACON, SMA has been successfully deployed at a total of eight locations.

SMA benefits, although primarily qualitative, are being experienced in varying degrees by all participating airlines. Many of these reported benefits have been translated into actual dollar savings by the airlines. The June 2000 Report also provides an estimation of dollar benefits based on reported diversions saved. The following provides a list of additional SMA benefits:

- Improved Situational Awareness to AOCs,
- Reduced Aircraft Diversions,
- Reduced Phone Coordination with FAA TMU,
- Improved Planning for Missed Approaches, and
- Improved Ground Operations (including gate management).

In the June and December 2000 reports, it was stated that US Airways identified many benefits from the SMA ARTS III flight display in observing terminal flight operations at Philadelphia (PHL). Specifically, these benefits include a possible reduction in diversions due to timelier information contributing to better tactical decision making, especially under irregular operations.

US Airways also stated that they have expanded the SMA data to the US Airways ramp tower at PHL and the LaGuardia International Airport (LGA) ramp tower. Recently, US Airways initiated an SMA working group to look at additional ways to use and promote the ARTS III data.

In addition to US Airways, positive feedback has been voiced by United, TWA, and Northwest airlines. Even the ATCSCC has been using the ARTS III data to improve situational awareness at certain SMA airports.

6.0 REFERENCES

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2. Free Flight Program Office, “FFP1 Performance Metrics to Date: June 2000 Report,” June 2000.
3. Free Flight Program Office, “FFP1 Performance Metrics to Date: December 2000 Report,” December 2000.
4. Free Flight Program Office, “Free Flight Phase 1 Performance Metrics: An operational Impact Evaluation Plan,” August 1999.
5. Conover, W.J., *Practical Nonparametric Statistics*, New York: John Wiley, 1980.

7.0 ACRONYMS

AAR	Airport Acceptance Rates
AM	Amendment
AOC	Airline Operations Center
ARTS III	Automated Radar Terminal System version III
ARTCC	Air Route Traffic Control Center
ASP	Arrival Sequencing Program
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATL	Atlanta Hartsfield airport
BNA	Nashville International Airport
CAASD	Center for Advanced Aviation System Development
CCB	Configuration Control Board
CCLD	Core Capability Limited Deployment
CHI	Computer Human Interface
CNAC	Center for Naval Analysis Corporation
CODAS	Consolidated Operations and Delay Analysis System
CR	Collaborative Routing
CTAS	Center TRACON Automation System
DIA	Denver International Airport
DR	Discrepancy Report
DU	Daily Use
EDCT	Estimated Departure Clearance Time
ETMS	Enhanced Traffic Management System
ETT	Estimated Time to Touchdown
EWR	Newark
FAA	Federal Aviation Administration
FADE	FAA's Airline Data Exchange
FFP1	Free Flight Phase 1
FFPO	Free Flight Program Office
FL	Flight Level
FSM	Flight Schedule Monitor
GAL	Gallon
GDP	Ground Delay Program
GDP-E	Ground Delay Program Enhancements
GPD	Graphic Plan Display
HID	Host Interface Device
IDU	Initial Daily Use
IFR	Instrument Flight Rules
IPE	Integrated Predictive Error
LAX	Los Angeles International Airport

LB	Pound
LGA	LaGuardia International Airport
MIT	Miles-in-Trail
MSP	Minneapolis/St. Paul
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASSI	National Air Space Status Information
NATCA	National Air Traffic Controllers Association
NCDC	National Climactic Data Center
NEXTOR	National Center of Excellence for Aviation Operational Research
nmi	Nautical mile
NRP	North American Route Program
NWA	Northwest Airlines
OAG	Official Airline Guide
PCA	Planned Capability Available
pFAST	Passive Final Approach Spacing Tool
P-GUI	Planview Graphical User Interface
PHL	Philadelphia International Airport
RBS	Ration-by-Schedule
SCT	Southern California TRACON
SMA	Surface Movement Advisor
SOC	Systems Operation Center
SUA	Special Use Airspace
T-GUI	Timeline Graphical User Interface
TMA	Traffic Management Advisor
TMU	Traffic Management Unit
TOC	Top of Climb
TOD	Top of Descent
TPs	Trial Plans
TRACON	Terminal Radar Approach Control Facility
URET	User Request Evaluation Tool
VFR	Visual Flight Rules
WAFDOF	Wrong Altitude For Direction Of Flight
ZDV	Denver Center
ZID	Indianapolis Center
ZME	Memphis Center
ZMP	Minneapolis Center

APPENDIX A. DESCRIPTION OF BOX PLOT

Box plots are used to graphically depict the range and shape of the distribution of a data sample. The central box represents the interquartile range containing 50 percent of the values. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers. A line across the box indicates the median, which is the middle of a distribution (half the scores fall above the median and half fall below).

Figure A-1 presents an example of a box plot. The shaded box stretches from the lower hinge (defined as the 25th percentile) to the upper hinge (the 75th percentile). This box contains the middle half of the observations in the distribution. Therefore, one quarter of the distribution is between this line and the top of the box and one quarter of the distribution is between this line and the bottom of the box.

The "H-spread", or interquartile range, is defined as the difference between the hinges. A "step" is defined as 1.5 times the H-spread. Inner fences are 1 step beyond the hinges. Outer fences are 2 steps beyond the hinges. The whiskers extend from the ends of the box to the outermost data point that falls within the upper (+1.5 * interquartile range) or lower (-1.5 * interquartile range) fences. In the box plots presented here, outliers are defined as values between the inner and outer fences, and are plotted with open circles. Extreme values are those outside the outer fences, and are plotted with asterisks.

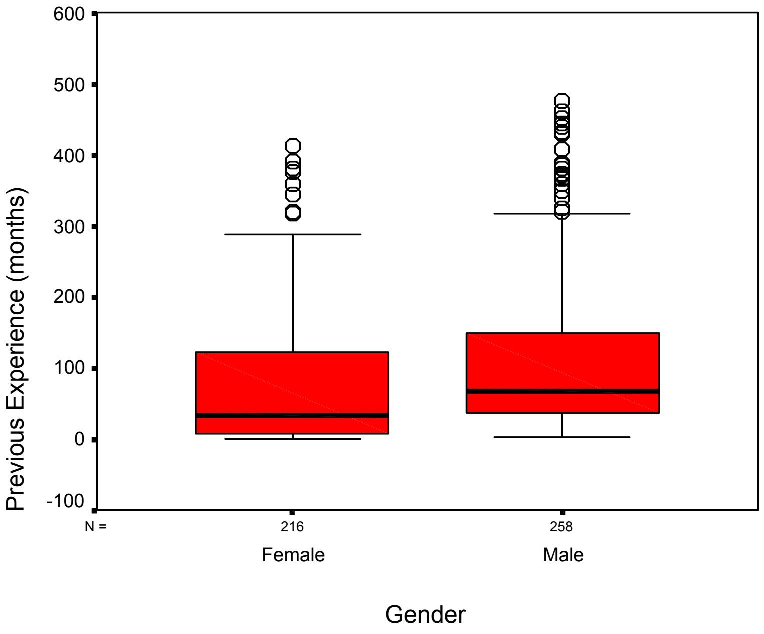

Figure A-1. Sample Box Plot

Within a display (such as that presented in Figure A-1), box plots are shown side by side for each of the groups defined by a factor (variable). The factors for Figure A-1 are "Female" and "Male." This display is particularly useful when the different variables represent a single characteristic measured at different times. Above the names of the factor labels ("Female" and "Male" in Figure A-1), the sample sizes (N) are presented, which indicate the number of data points included in the sample.

In examining Figure A-1, the sample on the right has a slightly higher median than the sample on the left. In addition, the whiskers extend further from the box showing that the data (excluding outliers) is more spread out than the sample on the left. Where one whisker and its outliers extend further than the other whisker and outliers in the same sample, the sample is skewed in the direction of the longer whisker. In Figure A-1, the whiskers for both boxes are positively skewed. Lastly, the sample on the right has many more outliers extending above the upper whisker. No outliers are found below the lower whisker since each lower whisker extends to zero, and months of experience must have a non-negative value.

It is often useful to compare data from two or more groups by viewing box plots from the groups side by side. Figure A-2 presents such an example. Plotted are the same data from Figure A-1 with an additional variable for comparison. Whereas Figure A-1 presents summary data on previous work experience (in months) by gender only, Figure A-2 provides the additional variable Minority Class. This offers a view that facilitates the comparison of data across multiple variables.

The data sample for Minority Class (Yes) yields longer boxes with whiskers that are more spread out and having a positive skew. A positive skew indicates that the mean (not shown) is higher than the median. This example also illustrates the outliers and extreme values for each grouping; the Minority Class groupings (Yes) display fewer outliers and extreme values.

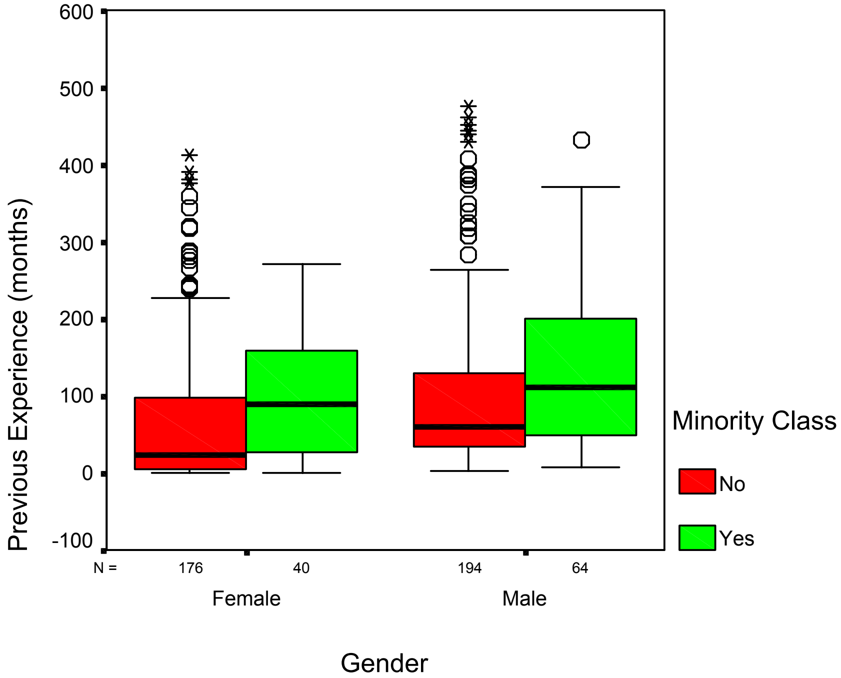

Figure A-2. Side-by-Side Box Plot Comparison